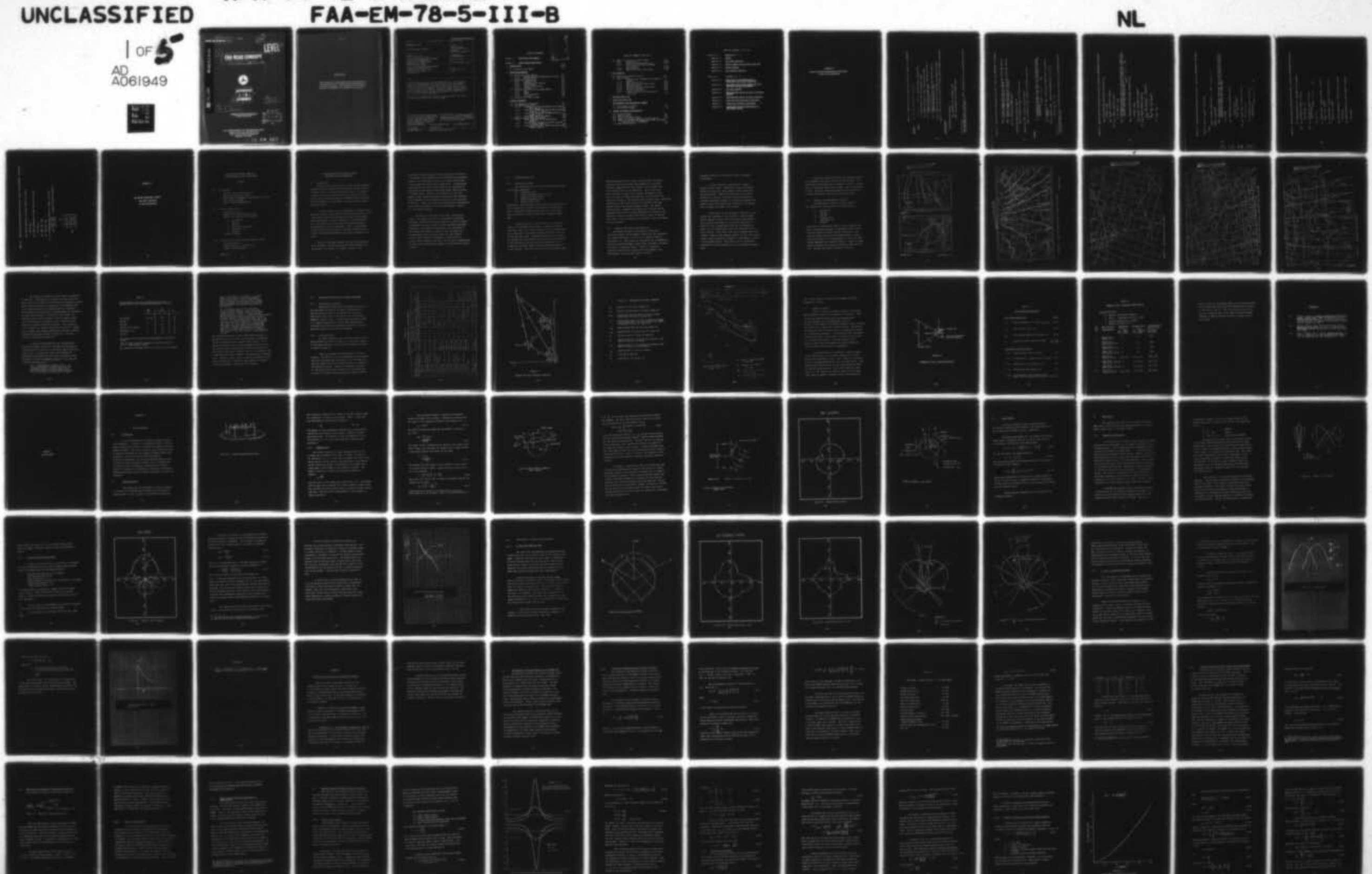
AD-A061 949 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C OFFIC--ETC F/G 17/7
FAA BCAS CONCEPT. VOLUME III B. APPENDICES F - M,(U)
APR 78 E J KOENKE
UNCLASSIFIED FAA-EM-78-5-III-B NL

1 OF 5
AD
A061949



SIFIED

1 OF 5

AD
A061949

14

REPORT NO. FAA-EM-78-5 - III-B

B.S. 12

LEVEL III

6

FAA BCAS CONCEPT.

Volume III B.

APPENDICES
F — M

11 APRIL 1978

12 323 p.

10

E. J. Koenke

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Systems Engineering Management
Washington, D.C. 20591

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FAA-EM-78-5, III-B		

4. Title and Subtitle	5. Report Date
FAA BCAS Concept, Appendices	April 17, 1978
	6. Performing Organization Code: AEM-20
7. Author(s): Koenke, E. J., et al	8. Performing Organization Report No.: FAA-EM-78-5
9. Performing Organization Name and Address: Office of Systems Engineering Management, Department of Transportation, Federal Aviation Administration, Washington, D.C. 20591	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: Office of Systems Engineering Management, Department of Transportation, Federal Aviation Administration, Washington, D.C. 20591	13. Type of Report and Period Covered
	14. Sponsoring Agency Code: AEM

15. Supplementary Notes

16. Abstract

A unique airborne aircraft collision avoidance system concept is presented which assures adequate separation from the largest possible percentage of potential collision threats. The concept operates in all airspace as a compatible backup to the present and evolving ATC system, and is acceptable to the pilot and the user community. The system concept capitalizes on the aviation community's large existing investment in ATCRBS transponders and on the ground based beacon surveillance system network for the basic sources of the collision avoidance information.

The report is contained in three volumes; an Executive Summary (I), Concept Description (II) and Appendices (III-A & III-B)

17. Key Words	18. Distribution Statement
Air Traffic Control Radar Beacon System, Discrete Address Beacon System, Beacon Collision Avoidance System, Transponder, Garble, Fruit, Radar Coverage, Traffic Density, Directional Antenna	Unlimited Availability Document may be released to the National Technical Information Service, Springfield VA. 22161 for sale to the public

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

For complete abstract see AD-A061 948.
Appendices in this volume include:

TABLE OF CONTENTS (continued)

APPENDIX F

PASSIVE POSITION DETERMINATION PROCEDURE, SINGLE SITE ATCRBS/RBX

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX

Measure: τ_1, δt_1, t_{oS}, t_{oT}, $\{t_1(i)\}$, $\{t_{2+3}(i)\}$

where $i = 1, 2, \cdots N^*$: N = maximum number of sweeps/scan

τ_1 = Time of most recent interrogation of RBX

δt_1 = Round trip time of BCAS interrogation of RBX

t_{oS} = Time of arrival of most recent RBX squitter prior to ATCRBS interrogation of BCAS

t_{oT} = Time of arrival of most recent RBX squitter prior to ATCRBS interrogation of target

$t_1(i)$ = Time of arrival of i^{th} mainbeam interrogation of BCAS

$t_{2+3}(i)$ = Time of arrival at BCAS of i^{th} target reply to ATCRBS interrogation

Data Received:

Decoded from RBX squitter:

W_R = Rotation rate of ATCRBS beacon

PRF = Interrogation rate of ATCRBS beacon

---

* Because ATCRBS round reliability is <100%, measurements may not be available for some of the indicated values of the index i.

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX (Continued)

ACP_S = Azimuth change pulse count at time of most recent RBX squitter prior to ATCRBS interrogation of BCAS

ACP_T = Azimuth change pulse count at time of most recent RBX squitter prior to ATCRBS interrogation of target

*(e) h_B = Altitude of ATCRBS beacon

Decoded from target aircraft replies:

$h_T(i)$ = Altitude of target in i^{th} Mode C reply

Decoded from RBX aircraft altitude encoder:

$h_S(i)$ = Altitude of BCAS aircraft at i^{th} Mode C reply time

Compute:

$\hat{t}_1$ = Centermark-estimated time of arrival of (hypothetical) beacon interrogation of RBX when RBX lies at center of main beam; computed from

$$\{t_1(i) : i = 1, 2, \cdots N\}$$

$\mathring{\rho}_{01}$ = Range rate of RBX aircraft from ATCRBS beacon (provided by tracker)

(a) ρ_{01} = Range of RBX aircraft from ATCRBS beacon at time $\hat{t}_1$

$$= c\delta t_1/2 + \mathring{\rho}_{01}(\hat{t}_1 - \tau_1)$$

---

* Letter designators such as (e) before equations designate the corresponding equation in the text (Section 3).

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX (Continued)

α_{BS} = Squittered main beam angle received at t_{oS}

$= 0.0879^{o} * ACP_K$

$\mathring{\alpha}_{10} = d\alpha_S/dt$ (provided by tracker)

(b) α_{10} = BCAS azimuth at time $\hat{t}_1$

$= \alpha_S + W_R(\ddot{t}_1 - t_{oS})$

$\hat{t}_{2+3}$ = Centermark-estimated time of arrival of (hypothetical) target reply at BCAS to an interrogation received by target when target lies at center of main beam; computed from

$$\{t_{2+3}(i) : 1, 2 \cdot \cdot \cdot N\}$$

α_{BT} = Squittered main beam angle received at t_{oT}

$= 0.0879° * ACP_T$

$\mathring{\alpha}_{1T} = \alpha_{1T}/dt$ (provided by tracker)

(c) α_{1T} = Target azimuth at time $\hat{t}_1$

$$= \begin{cases} \alpha_{BT} + W_R\,(\hat{t}_{2+3}-t_{oT}) - \mathring{\alpha}_T(\hat{t}_{2+3}-\hat{t}_1) \\ \alpha_S + (W_R - \mathring{\alpha}_T)\,(\hat{t}_{2+3}-\hat{t}_1) \end{cases}$$

$\Delta\alpha = \alpha_{1T} - \alpha_{10}$

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX (Continued)

$$N_{12}(i) + \varepsilon_{12}(i) = [t_{2+3}(i) - t_1(i)] * PRF$$

where

$N_{12}(i)$ = nearest integer value ($\pm$) , and $0 < \varepsilon_{12}(i) << 0.5$

$\Delta TOA(i) = \varepsilon_{12}(i)/PRF$

$\Delta\hat{TOA}$ = Centermark-estimated differential time of arrival between arrival of target reply at BCAS and BCAS reply time computed as though both aircraft are interrogated on same sweep

$\Delta\rho = c * \Delta\hat{TOA}$

ρ_{1T} = Range beacon to target at time $\hat{t}_1$

$$= \frac{\Delta\rho(\rho_{1T} + \rho_{10})}{2[\Delta\rho + \rho_{10}(1 - \cos\Delta\alpha)]}$$

(d) ρ_{0T} = Range BCAS to target at time $\hat{t}_1$

$= \Delta\rho + \rho_{10} - \rho_{1T}$

$\hat{h}_T$ = Altitude of target at time $\hat{t}_{2+3}$

computed from

$$\{h_T(i);\ i = 1, 2, \cdots N\}$$

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX (Continued)

$\mathring{h}_T$ = Target altitude rate (provided by the tracker)

(f) h_T = Altitude of target at time $\hat{t}_1$:

$= \hat{h}_T + \mathring{h}_T(\hat{t}_{2+3} - \hat{t}_1)$

(g) h_S = Altitude of BCAS at time $\hat{t}_1$:
computed from $\{h_S(i);\ i = 1, 2, \cdots N\}$

$\Delta h = h_S - h_T$

d_1 = Ground range -- beacon to BCAS at time $\hat{t}_1$

$= \left[\rho_{10} \quad (h_S - h_B)^2\right]^{1/2}$

d_2 = Ground range -- beacon to target at time $\hat{t}_1$

$= \left[\rho_{1T} - (h_S - h_B)^2\right]^{1/2}$

N_S = North coordinate of BCAS relative to beacon

$= d_1 \cos \alpha_{10}$

E_S = East coordinate of BCAS relative to beacon

$= d_1 \sin \alpha_{10}$

Table F-1: Passive Position Determination Procedure, Single Site ATCRBS/RBX (Continued)

N_T = North coordinate of target relative to beacon

$= d_2 \cos \alpha_{1T}$

E_T = East coordinate of target relative to beacon

$= d_2 \sin \alpha_{1T}$

$\sigma_N = \text{sgn}\ (N_T - N_S)$

$\sigma_E = \text{sgn}\ (E_T - E_S)$

(h) β = Target bearing relative to BCAS at time $\hat{t}_1$

$= \tan^{-1} \left[\frac{E_T - E_S}{N_T - N_S} \right]$ quadrant assigned according to

		σ_E –	σ_E +
σ_N	+	II	I
σ_N	–	III	IV

APPENDIX G

SSR NORTH DIRECTIONAL ERRORS AND THEIR INFLUENCE ON BCAS PERFORMANCE

SSR NORTH DIRECTIONAL ERRORS AND
THEIR INFLUENCE ON BCAS PERFORMANCE

OUTLINE

G-1. Introduction

- Specific concern and perspective
- Directional errors in general
- Basic nature of magnetic directional error problem
- Use of ASR's and ARSR's
- Effect on BCAS implementations

G-2. SSR Directional Errors

- Definition of terms
- Magnetic declination characteristics
- Analysis of representative locations
    - a. Los Angeles
    - b. Chicago
    - c. New York
    - d. Atlantic City (NAFEC)
    - e. Washington, D.C.
    - f. Houston
- Summary of results

G-3. Directional Error Effect on Performance of BCAS

- Geometry involved
- Error analyses for selected cases
- Summary and conclusions

References

SSR NORTH DIRECTIONAL ERRORS AND THEIR
INFLUENCE ON BCAS PERFORMANCE

G-1. Introduction

During the past several years, the FAA and the industrial community have been investigating and testing various means for providing air-to-air collision avoidance service. A recently configured class of systems which bases its viability on the current (and continuing) widespread implementation of the radar beacon transponder is called BCAS, for Beacon-based Collision Avoidance System.

The BCAS technique can be implemented in a number of ways, depending upon the measurement data utilized by the system. The system can be passive, by receiving data from various sources (SSR interrogators, airborne transponders, other BCAS units) or it can operate in an active mode by transmitting beacon interrogations to other transponders. There is considerable flexibility in the design options available for BCAS since a variety of measurement parameters can be made available to the system.

Several of the BCAS candidate designs use measurements of the azimuth of the protected aircraft (BCAS equipped) and the azimuth of the threat, or "target" aircraft. This

information is made available to the aircraft in the vicinity of the SSR by the transmission by the SSR (sidelobe suppression antenna) of a coded pulse of RF energy, called a North pulse, as the antenna main beam passes through North. Conventionally, the Air Route Surveillance Radars (ARSR's) are calibrated to true North and the Airport Surveillance Radars (ASR's) are set to magnetic North. However, the variability of the local magnetic North direction with both location and time indicates that substantial errors in magnetic North may occur especially at ASR sites. These errors can cause BCAS position determination errors which may degrade or limit the performance of some or all of the BCAS techniques

The purpose of this paper is to first, describe the nature of the magnetic variation or declination conditions throughout the United States with emphasis on several selected hign density locations in CONUS; second, determine reasonable estimates for the magnetic declination errors applicable to the selected high density locations; third, determine the corresponding position location errors for these angular errors; fourth, assess the influence of these errors on selected BCAS techniques; and fifth, provide some recommendations for improving or avoiding the magnetic declination error effects of SSR's.

G-2 SSR Directional Error

G-2.1 Definition of Terms

The directional errors of SSR's may be separated into the following components:

a) calibration error
b) azimuth encoding round-off errors
c) transmission delay error
d) North determination error
e) magnetic North error

Additionally, user and threat (target) position location errors can be caused by the difference in magnetic North direction (due to declination changes) between two sites since there exists no fixed or consistent directional reference between them.

Calibration error is the inaccuracy in setting the center of the mainbeam of the radar to a desired reference direction. This error can be large but with care and attention can be made small. The azimuth encoding round-off error also is typically very small. Transmission delay error is simply the azimuth error introduced at the receiving location caused by the time delay associated with the propagation of the azimuth and reference signals from the transmitting site to to the receiver. This error also is normally negligibly small.

North determination error relates to the accuracy with which true North can be determined, which generally is excellent. Similarly, magnetic North error relates to the accuracy with which magnetic North can be determined. This is also very good, resulting in small errors, however the magnetic North direction tends to change with time and is not consitent from location to location. The variation with location causes significant differences in the direction which two aircraft in the same general vicinity may perceive magnetic North. The general characteristics of magnetic declination are discussed and the magnitude and direction of these differences are anlyzed in the following section for several high density regions of concern. After this, a brief evaluation of the effects of these difference will be presented.

G-2.2 Magnetic declination Characteristics

The overall variation of the magnetic declination (differnce between true and magnetic North) over the continental U.S. ranges from about 21 W to 21 E, a change of some 42 (Reference G-1). Mean values for declination from a mathematical model are plotted on magnetic charts which are readily available from the U.S. Geological Survey. There is a systematic variation in declination caused by the displacement of the North magnetic pole from true North, as well as

irregular variations in declination causes by regional disturbances.

In local regions the variations are normally charted as mean values. Additionally, there are moderate changes from the mean values caused by local disturbances and other effects. These local influences may be either artificial or natural; the latter being more significant. A natural disturbance example is the Northern Michigan iron deposits which cause appreciable variations in declination even at moderate altitudes in this region.

Daily changes in the declination occur due to solar effects and conditions in the ionosphere. These normally involve changes of about 1-2% of the normal earth magnetic field intensity and result in declination variations of about 0.25° for a magnetically quiet day to a maximum of about 1-2° for a magnetically active day (primarily due to solar effects). This latter value may be exceeded about once a month. However, these are gross effects, in that a very large region, usually the entire continent, is influenced in a more or less uniform manner. This effect is not a significant contribution to the differential error in declination between sites.

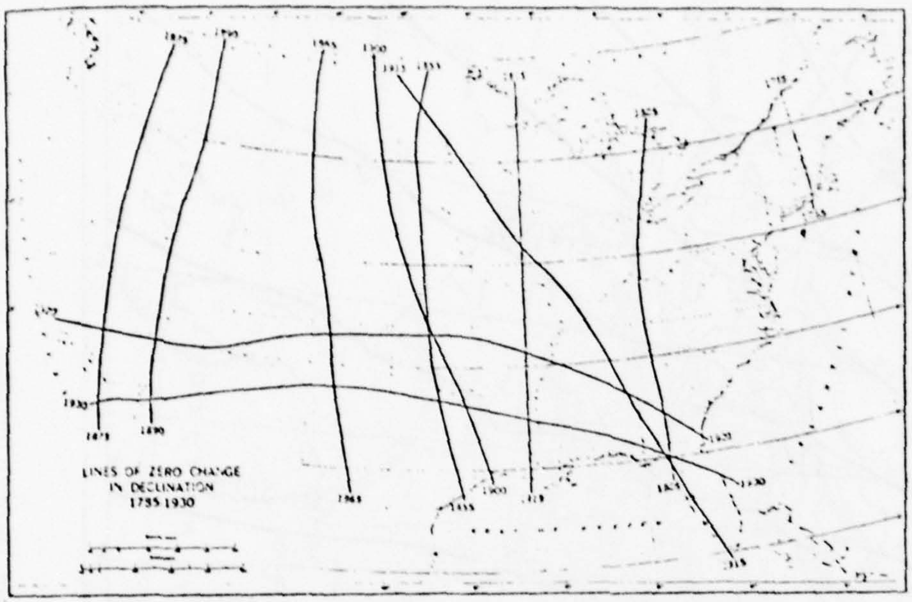
Figures G-1 and G-2 illustrate the changing character of the magnetic field with time for the United States. The zero magnetic declination line is shown as it moved - significantly - during the past several decades. Data is shown back to 1785. Figure G-3 shows the variability with location of the equal declination contours for the United States.

6.2.3 Analysis of Representative Locations

Determinations of nominal values of magnetic declinations were obtained for the following regions.

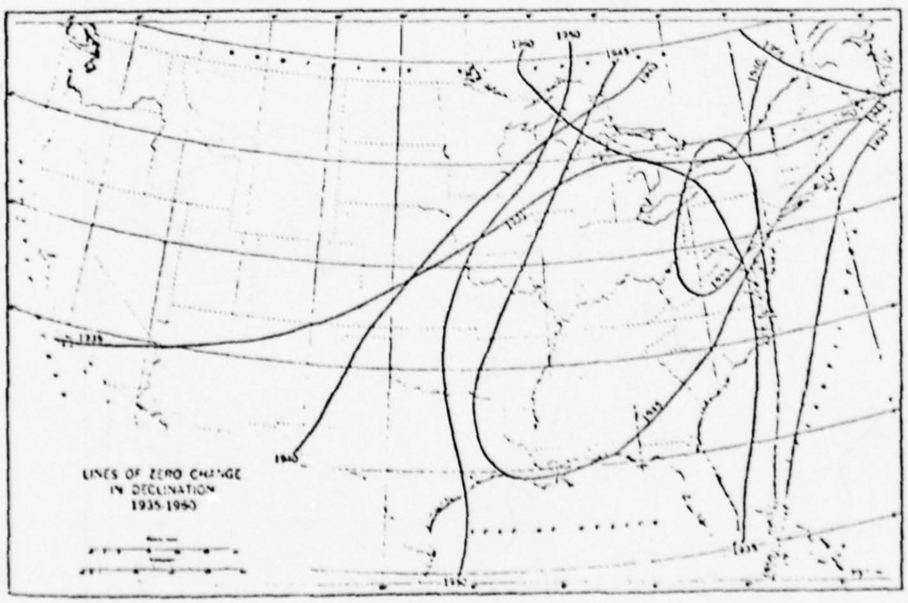
a. Los Angeles
b. Chicago
c. New York
d. Atlantic City
e. Washington, D.C.
f. Houston

Figure G-4 is a declination chart for the Los Angeles area which illustrates the changes in declination with location. The chart shows the distance (20 nmi) which needs to be travelled along the direction of maximum change to cause a deviation of about 0.15°, corresponding to the typical ASR antenna beamwidth (as a reference figure). Figure G-5 shows similar information for Chicago, Washington, NAFEC and New York. The data for Houston is shown in Figure G-6.



—Positions of the line along which annual change of magnetic declination in the United States was zero, at various epochs from 1785 to 1930.

FIGURE G-1



—Positions of the line along which annual change of magnetic declination in the United States was zero, at various epochs from 1935 to 1960.

FIGURE G-2

(REFERENCE G-2)

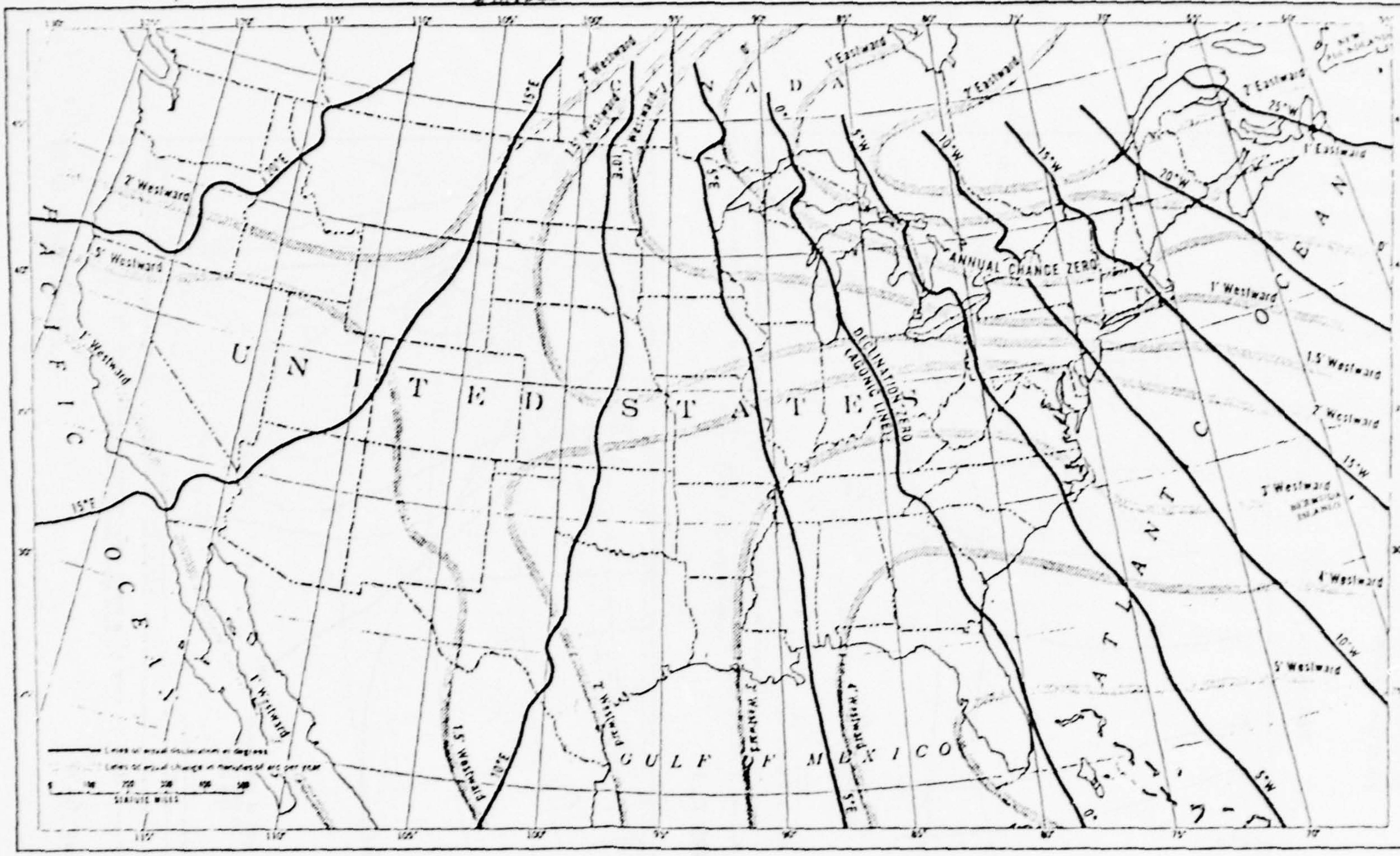


FIGURE G-3: EQUAL DECLINATION CONTOURS FOR THE UNITED STATES

(Reference G-2)

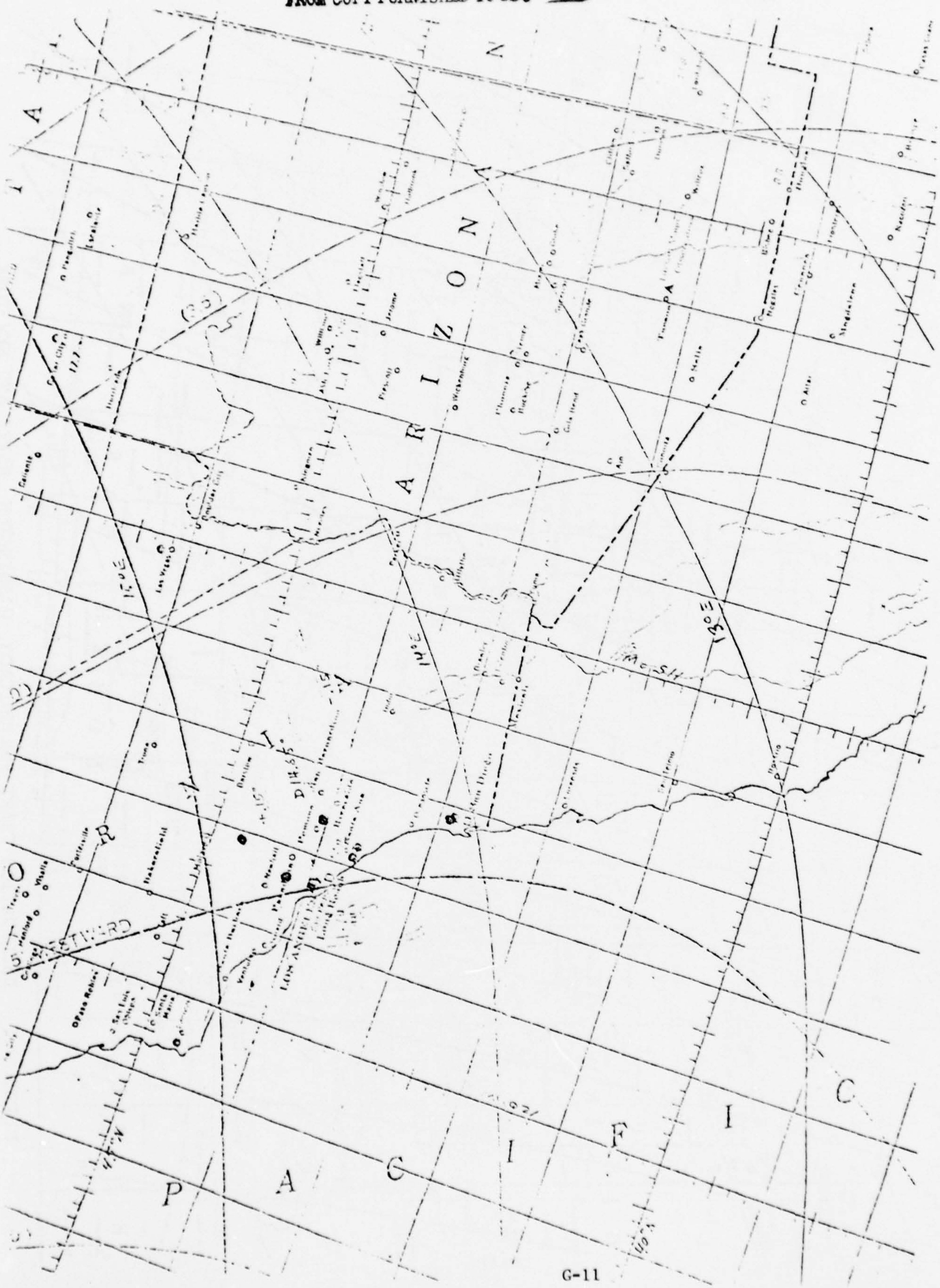


FIGURE G-4: DECLINATION CHART FOR LOS ANGELES

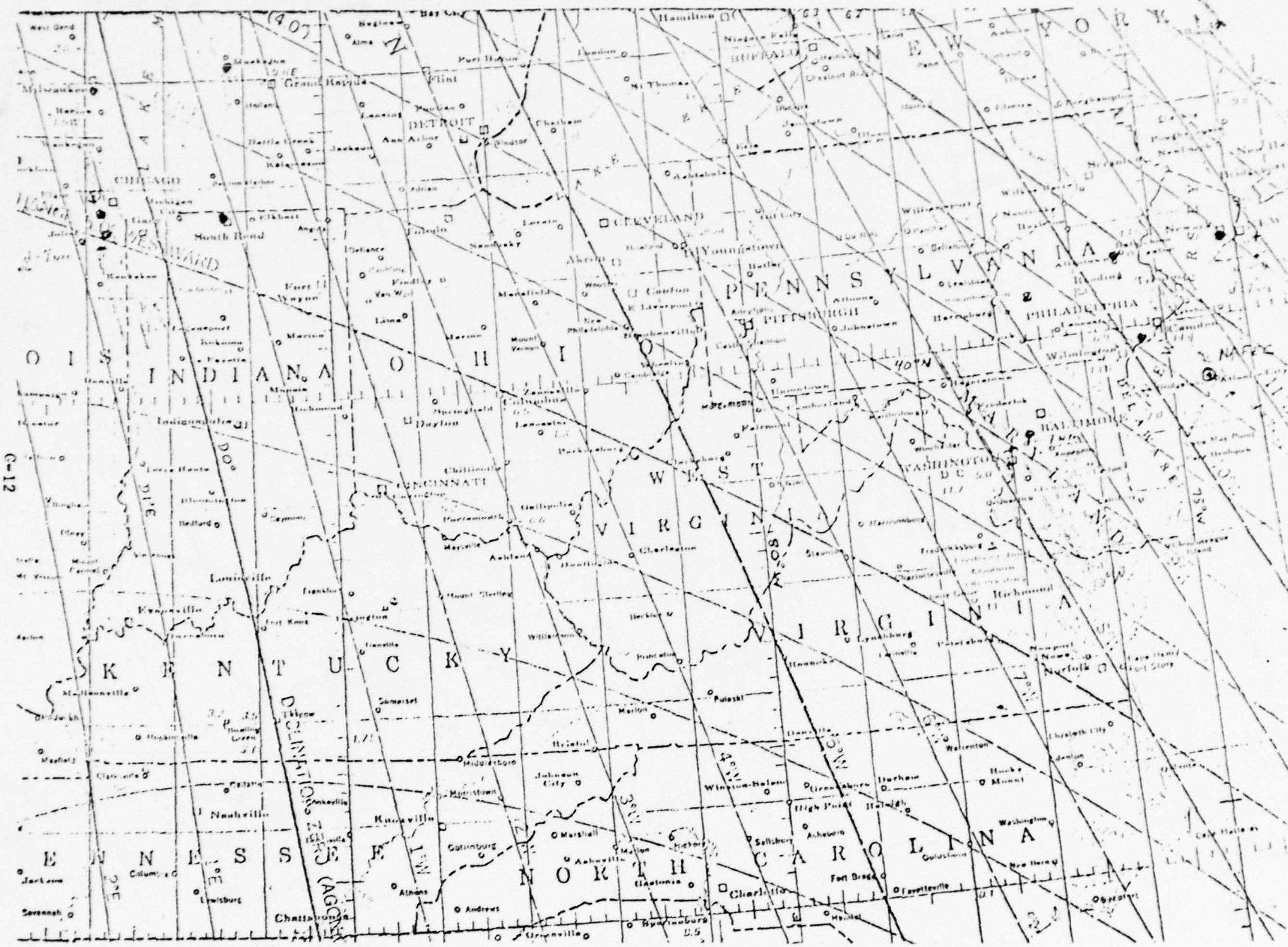


FIGURE G-5: DECLINATION CHART FOR CHICAGO, WASHINGTON, NAFEC AND NEW YORK

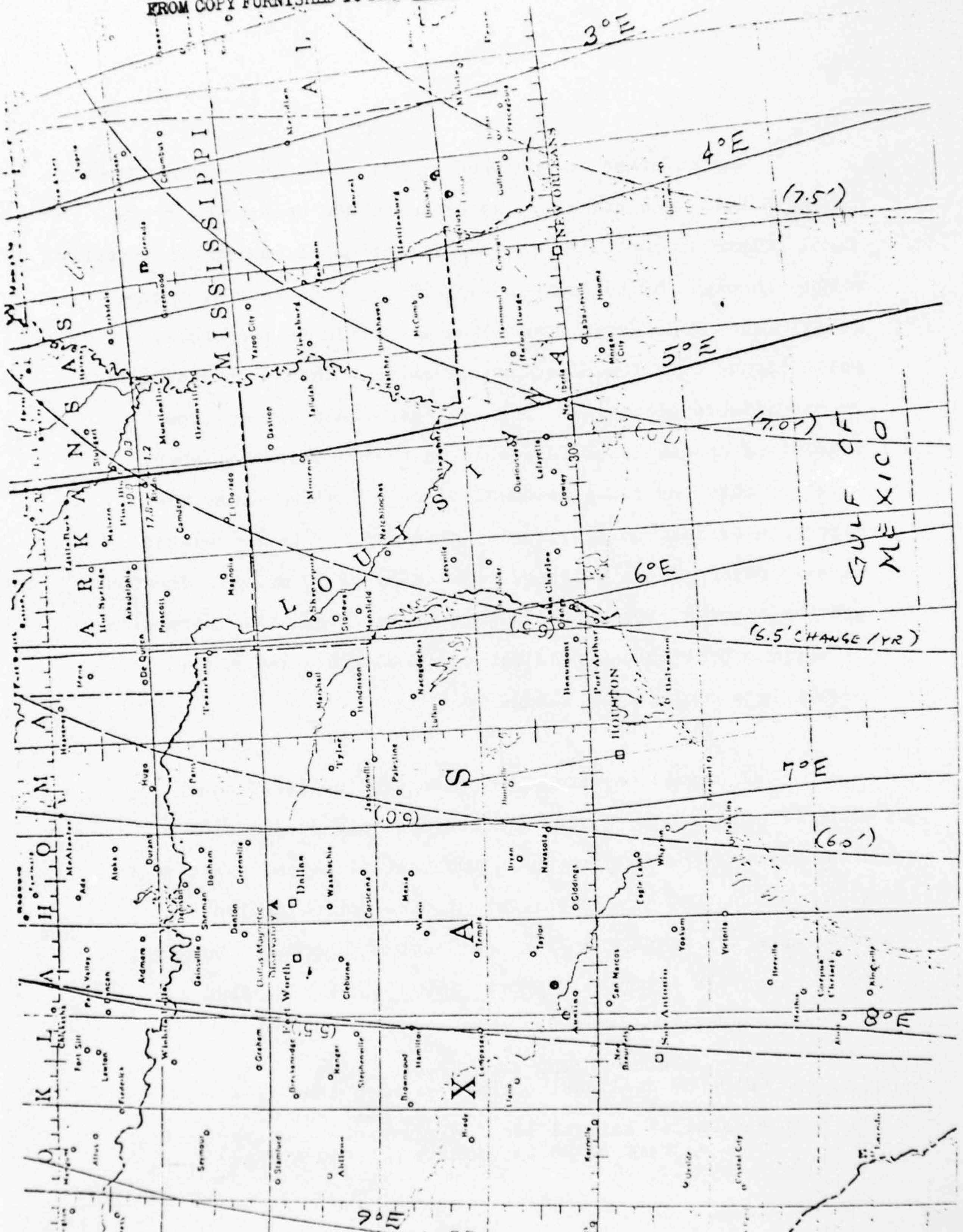


FIGURE G-6: DECLINATION CHART FOR HOUSTON

The information obtained from the charts is summarized in Table G-1. Additionally, an estimate has been made in the final column of the table for the direction of maximum air traffic moving through the region. Surprisingly, this indicates that in all cases considered, the maximum traffic is reasonably well-aligned with the direction of maximum change in declination - an undesirable situation. For the East coast cities, the conditions appear least favorable in that a change of about 0.14° is obtained for a movement of only 7 miles along the direction of maximum declination gradient. This correlates to a 1° change for a distance separation of 50 miles. Houston and Los Angeles area distance separations along the direction of maximum declination gradient of about 120 - 140 miles result in a declination change of 1°.

It should be recognized that the indicated chart value (of an isogonic chart) for the magnetic declination of a location may be in error by a substantial amount relative to actual value. To stress this point, the following two paragraphs are excerpted from the Coast and Geodetic Survey Publication 718 entitled Magnetic Surveys, by H.H. Howe and L. Hurwitz (Reference G-3):

> "84. Interpreting an isogonic chart. - A value of declination that has been read from an isogonic chart is called a chart value. Because of natural local disturbance (see par. 47), a chart value is usually not the actual

TABLE G-1

Maximum Magnetic Declination Change Characteristics for Selected Cities with Estimated Maximum Traffic Direction

	$d(\theta)$ n.m.	θ Deg's AZ.	θ_T
Los Angeles	20 n.m.	150	140
Chicago	7	75	90
New York	7	65	75
Atlantic City (NAFEC)	7	65	60
Washington, D.C.	7	65	45
Houston	17	85	90

θ, Orientation of direction of maximum magnetic declination change

$d(\theta)$, Distance along θ for magnetic declination change of of 0.14 (Beam Width of radar)

θ_T, Direction of maximum traffic at various cities (estimated)

value of declination. Instead, it is roughly equal to the average for an area centered at the point, with a radius -f some 10 miles. There is perhaps an even chance that the chart value will agree with the actual value within one-half degree; occasionally, they differ by many degrees.

85. An extreme case of such a difference occurs at Rison, Arkansas. The chart value (scaled from our isognonic chart of the United States for 1960) is 6 42' E. **There are nine places** within a few miles of Rison at which declination has been measured; the observed values at these stations (reduced to 1960) range from 1 39' E. to 21 15' E. It is not practical to show each of the nine observed values on the chart - and if we did, they would still be of little use in estimating that value at a point where no observations had been made. The best value to use for any point near Rison, lacking observations at the exact point, is the chart balue of 6 42' E. Obviously, the compass is not very reliable in that particular region."

The important point here is that actual measured values of declination (such as at radar sites) may have a substatially greater variation than the average of chart values. It is unlikely that many places will show changes of nearly 20 in the measured values of declination at various locations in a local area as near Rison, Arkansas, but it is not unlikely that a small fraction of this (perhaps a few degrees) may frequently occur. The use of chart values is clearly an optimistic, and possible unrealistic, approach if one intends to accurately establish the magnetic declination of a location.

G-3. Directional Error Effects on BCAS Performance

6.3.1 Determination Techniques

Analyses were undertaken to determine the effect of the anticipated differences in magnetic declination for selected regions as well as the various site peculiar directional errors such as calibration errors and antenna beamwidth accuracy errors. The work was done both by means of a computer simulation for various BCAS implementation techniques and verified by geometrical analyses of selected operating conditions for the BCAS techniques.

G-3.2 Cases Considered

The BCAS simulation cases considered with the parameters measured are shown in Table G-2. The general geometry for the BCAS technique, indicating the measurements involved is shown in Figure G-7.

Table G-3 provides the nomenclature for the BCAS analyses. The details of the algorithms which were developed will not be presented but the particulars of the input data and test conditions will be provided as well as a summary of the simulation results. Figure G-8 illustrates the shift in the relative direction of radar site 2 resulting from an error in the North reference direction between S1 and S2,

TABLE G-2

BCAS SIMULATION ALGORITHMS AND INPUT PARAMETERS

Alg. No.	BCAS Operating Technique Description	Algorithm Title	Min. No. Radars for Oper.	Min. No. Targets for Oper.	Input Data ρ_{io}	α_{io}	$\Delta\alpha_{io}$	τ_{ij}	ρ_{orj}	β_{oj}	h_o	h_j	Notes Comments
1.	Single Site, Passive, ATCRBS	Single #7	1	1	X	X	X	X			X	X	
2	Single Site, Semi-Active, ATCRBS and DABS	Single #7	1	1	X	X		X	X		X	X	
3.	Single Site, Semi-Active, ATCRBS	Single #15	1	1		X	X	X	X		X	X	Litchford Single Site
4.	Single Site, Semi-Active ATCRBS and DABS	Single #20	1	1	X	X	X	X	X		X	X	
5.	Dual Site, Passive ATCRBS	Passive Dual #13	2	1	X	X		X			X	X	
6.	Dual Site, Semi-Active ATCRBS	Semi-Dual #13	2	1	X	X		X	X		X	X	
7	Dual Site, Semi-Active ATCRBS	Semi-Dual #26	2	1		X	X	X	X		X	X	Litchford Dual Site Semi-Active
8.	Dual Site, Passive ATCRBS, Transf. Alignmt	Passive Dual #32	2	1	X	X		X	X		X	X	
9.	Dual Site, Passive ATCRBS	Passive Dual ATCRBS	2	2			X	X			X	X	No Ranges or Angles
10.	Dual Site, Semi-Active ATCRBS	Semi-Dual ATCRBS	2	2			X	X	X		X	X	No Ranges or Angles to Sites
11.	Active Only	Active	0	1					X	X			On-Board Angle Meas. (Dir. Ant.)
12.	Dual Site, Passive ATCRBS	Passive Dual #26	2	1		X	X	X			X	X	Litchford Dual Site Passive

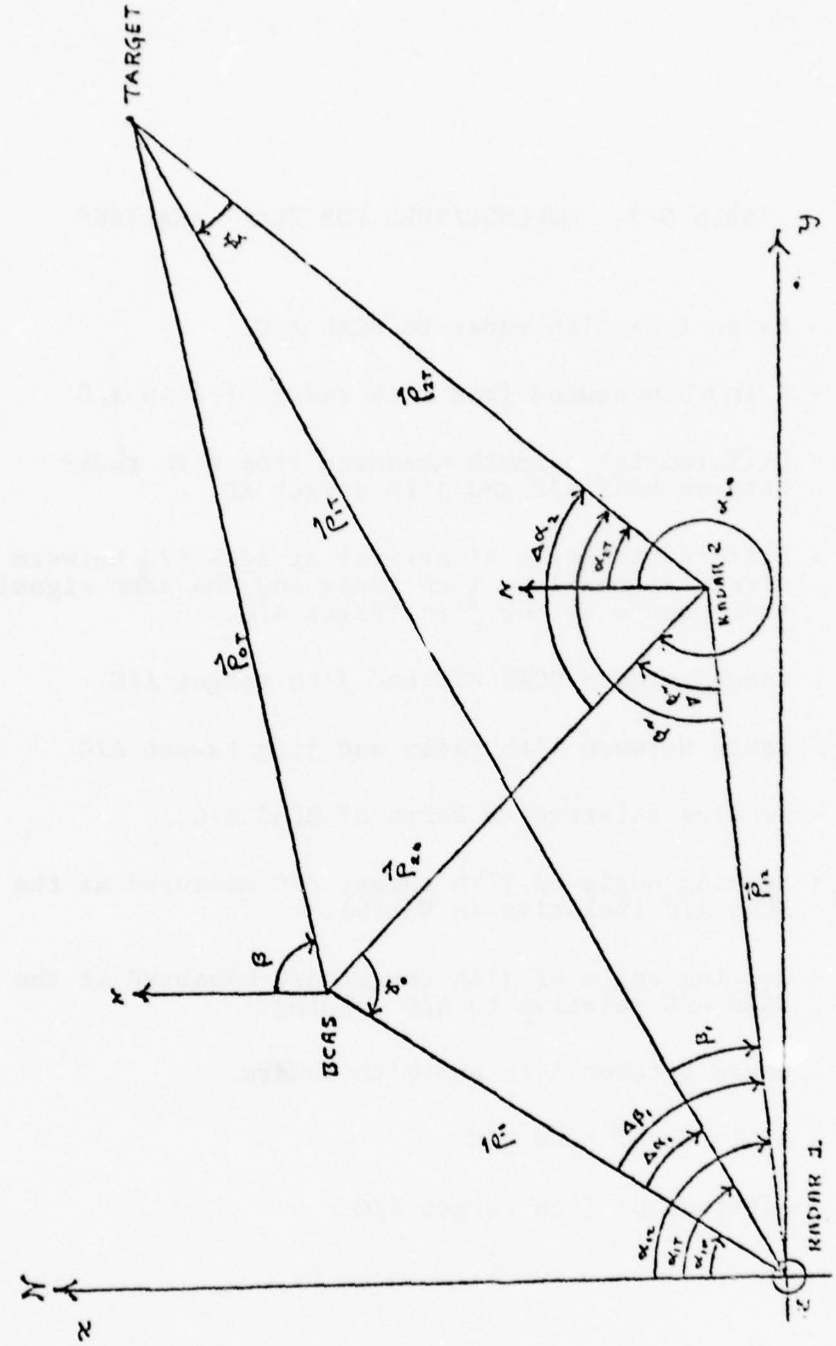


FIGURE G-7

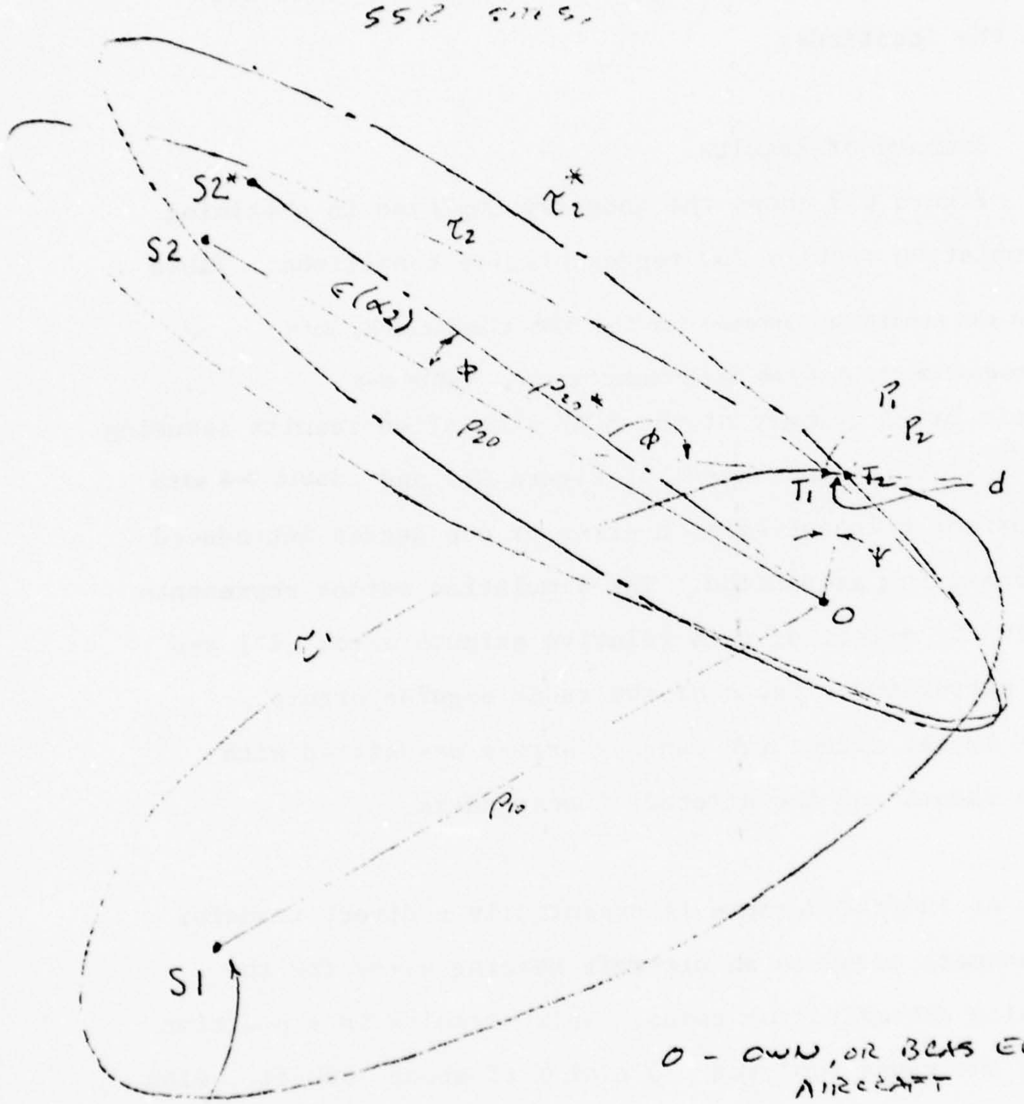
GEOMETRY FOR BCAS TECHNIQUE OPERATION

TABLE G-3: NOMENCLATURE FOR BCAS ANALYSES

ρ_{io}	-	Range from i'th radar to BCAS A/C.
α_{io}	-	Azimuth measured from i'th radar of BCAS A/C
$\Delta\alpha_{ij}$	-	Differential azimuth measured from i'th radar between BCAS A/C and j'th target AC.
τ_{ij}	-	Differential time of arrival at BCAS A/C between direct signal from i'th radar and the same signal transponded by the j'th target A/C.
ρ_{oTj}	-	Range between BCAS A/C and j'th target A/C.
ρ_{iTj}	-	Range between i'th radar and j'th target A/C
θ_o	-	Heading relative to North of BCAS A/C.
β_j	-	Bearing angle of j'th target A/C measured at the BCAS A/C (relative to North).
β_{oj}	-	Bearing angle of j'th target A/C measured at the BCAS A/C relative to A/C heading.
ρ_{ik}	-	Range between i'th and k'th radars.
h_o	-	Altitude of BCAS A/C.
h_j	-	Altitude of j'th target A/C.

FIGURE G-8

GEOMETRY FOR POSITION ERROR CALCULATIONS FOR BCAS TECHNIQUE - USING ΔTOA'S (τ_1, τ_2), ANGLES & RANGES TO SSR SITES (α_{10}, α_{20}), AND ANGLES FROM TARGET TO SSR SITES.



SECONDARY SURVEILLANCE RADAR SITE 1

O - OWN, OR BCAS EQUIPPED AIRCRAFT

T - THREAT, OR "TARGET" AIRCRAFT

T_1 - POSITION 1, ALIGNED WITH OS_2

T_2 - POSITION 2, ALIGNED WITH OS_2^*

such as that caused by a change in the magnetic deviation between the locations.

3.3 Summary of Results

Figure G-9 shows the geometry employed in obtaining BCAS simulation results for representative conditions. Table G-4 lists the conditions assumed for the BCAS simulations, both for the measurements and the measurement error. Table G-5 provides a brief summary of the BCAS simulation results assuming the conditions (as indicated) of Figure G-9 and Table G-4 with the important relative azimuth error of one degree introduced as a normalizing assumption. The simulation output represents basically the effect of this relative azimuth error (1°) and to some extent the effects of the radar angular errors and to a lesser extent the ranging errors associated with both the radars and the aircraft transponders.

As indicated, there is essentially a direct transfer of the azimuth error to an aircraft bearing error for the single-site determination cases. This results in a position error at the range employed (10 n.mi.) of about 1000 ft., with proportionally smaller errors as the range between the BCAS A/C and the target decrease. In the dual radar site cases (No's 5,6,7,12), there is no range to target error in those cases where the BCAS A/C actively provides this separately.

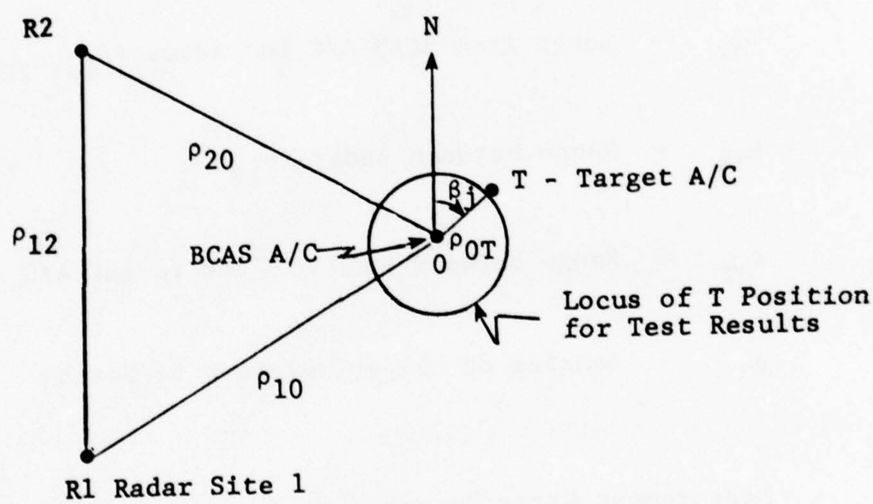


FIGURE G-9

GEOMETRY FOR BCAS SIMULATION RESULTS

TABLE G-4

BCAS SIMULATION CONDITIONS

Measurement/Description		Value
ρ_{io}	- Range from BCAS A/C to radars (ρ_{10}, ρ_{20})	50n.mi.
ρ_{ik}	- Range between radar (ρ_{12})	50n.mi
ρ_{0T}	- Range between BCAS A/C and target A/C	10n.mi
β_j	- Bearing of target relative to North	0 - 360° (5° steps)

Measurement Error/Description		
σ (α) -	Azimuth angular error of radars	0.18°
σ ($\Delta\alpha$)-	Differential AZ. angular error of radars	0.25°
σ (ρ) -	Ranging error, from radars or A/C	100'
σ (τ) -	Differential TOA ranging error	100'
σ $(\alpha)_N$ -	Azimuth angular error between radars Note: This is an arbitrary vlaue for reference.	1°

TABLE G-5

SUMMARY OF BCAS SIMULATION ERROR RESULTS

Assumed Conditions:

- Figure 9 Measurement Geometry
- Table 4 Measurement and Error Values
- Azimuth Angular Error of Radar 1 Relative to Radar Z of 1°.

ALG No.	BCAS Technique Description	Range Error $\sigma(\rho_{OT})$ Bias - Feet Av $\pm$ Range	Bearing Error $\sigma(\beta_{OT})$ Bias - Degrees Av $\pm$ Range	Position Error RSS$\sigma(\rho)+\rho\sigma(\beta)$ Bias-Feet Av $\pm$ Range
1	Single Site Passive (S-7)	0	1.0	1050
2	Single Site Semi-Active (S-9)	0	1.0	1050
3	Single Site Semi-Acitve (S-15)	0	1.0	1050
4	Single Site Semi-Active (S-20)	0	1.0	1050
5	Dual Site Passive (PD-13)	740 $\pm$ 575	0.74 $\pm$ 0.5	1190 $\pm$ 580
6	Dual Site Semi-Active (SD-13)	0	0.5 $\pm$ 0.35	530 $\pm$ 365
7	Dual Site Semi-Active (SD-26)	0	0.5 $\pm$ 0.32	530 $\pm$ 340
12	Dual Site Passive (PD-26)	810 $\pm$ 600	0.76 $\pm$ 600	1260 $\pm$ 600

However, there is a significant effect on the relative angular error between radar sites when TOA determination of position is used (cases 5 and 12). The total position error as the root sum of squares (RSS) of the range error and the range component of bearing error (at 10 n.mi.) is given in the last column.

REFERENCES

G-1. Fabiano, Eugene B., Magnetic Declination of the United States - Epoch 1975.0, Dept. of the Interior, U.S. Geological Survey Map I-911. Prepared in cooperation with the National Oceanographic and Atmospheric Administration, Reston, VA., 1975.

G-2. Nelson, James H., Louis Hurwitz and David G. Knapp, Magnetism of the Earth, U.S. Dept. of Commerce, Coast and Geodetic Survey, Publication 40-1, GPO, Washington, D.C., 1962.

G-3. Howe, H. Herbert and L. Hurwitz, Magnetic Surveys, U.S. Dept. of Commerce, Coast and Geodetic Survey, Serial No. 718, Third Edition, GPO, Washington, D.C., 1964.

APPENDIX H

THE BCAS ANTENNA

APPENDIX H

The BCAS Antenna

H.1 Introduction

A circular phased array for BCAS is studied in detail in this Appendix. In Section 2, a mathematical model of the antenna is formulated in order to calculate the antenna's far-field radiation pattern. This result is used in the following sections to study the performance of the antenna in various applications. In Section 3, the use of sum and difference beams is studied; on transmission, the sum and difference beams are used to limit the region of possible replies, and on reception the two beams are used for monopulse processing of the received signals. In Section 4, alternatives for monopulse interrogation using different beam forming procedures and signal structures are discussed.

H.2 Antenna Analysis

The antenna that has been modeled is shown in Figure 1. It consists of N omnidirectional elements that are uniformly spaced around a circle in front of a cylindrical ground plate.

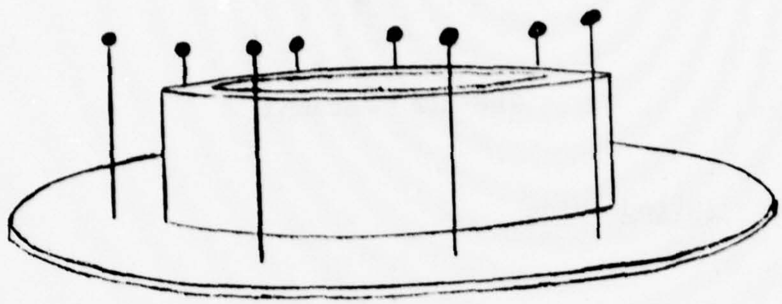


Figure H-1. Circular Phased Antenna Array

The cylindrical conductor has a radius R and each element stands at a distance d in front of the cylinder. Here, is the free spce wavelength at the operating frequency,

$$= \frac{c}{f} \qquad \text{(H.2.1)}$$

The antenna is to be operated as a phased array be individually controlling the RF phase at each element in both the transmit and receive mode. This phasing is used for syntheses of a desired pattern, ie, to steer a main beam and/or achieve given directivity.

H.2.1 Element Factor

The pattern created by a single element adjacent to the cylinder can be computed by the theory of images. In Ramo, et al, (Reference H-1), it is shown that to compute the fields in the region external to the cylinder, the combination of the element and the conducting cylinder is equivalent to the element and a single image of the element in the conducting cylinder. The image is located on a radial line through the element at a distance

$$r_i = \frac{R^2}{R+d}$$

from the center of the conducting cylinder (fig. H-2). The element and its image can be combined into single equivalent element which has a pattern associated withit, which is called the element factor. With this , the array can be represented by N such elements of proper orientation.

The equivalent element is located at the midpoint between the element and its image. Defining the distance from the center of the conducting cylinder to the element to be

$$r_e = (R+d)\lambda \tag{H.2.3}$$

the midpoint between the image and the element is located at $R_\phi \lambda$, where

$$\begin{aligned} R_\phi &= \frac{1}{2}(r_e+r_i) \\ &= \frac{R^2+(R+d)^2}{2(R+d)} \end{aligned} \tag{H.2.4}$$

The element factor, representing the pattern of the single equivalent element that represents the element and its image, depends on the spacing between the element and its image

$$\begin{aligned} r_s &= r_e-r_i \\ &= \frac{d(d+2R)\lambda}{d+R} \ . \end{aligned} \tag{H.2.5}$$

The distance from the element to the cylinder d can be chosen to yield any desired element - image spacing by solving (H.2.5) for d and obtaining

$$d = \left(R^2+\left(\frac{r_s}{2}\right)^2\right)^{\frac{1}{2}} - \left(R- \frac{r_s}{2}\right) \tag{H.2.6}$$

This value for d can be used to express the midpoint between the element and its image

$$R_\phi = R\left[1 + \left(\frac{r_s}{2R}\right)^2\right]^{\frac{1}{2}} \tag{H.2.7}$$

In Figure H-3, the calculation of the element factor is illustrated.
When radiation is at an angle θ, there is a phase difference of

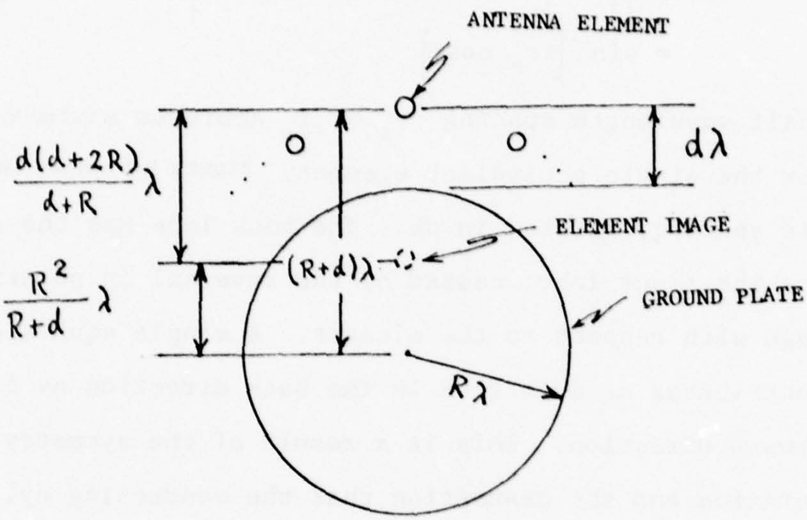


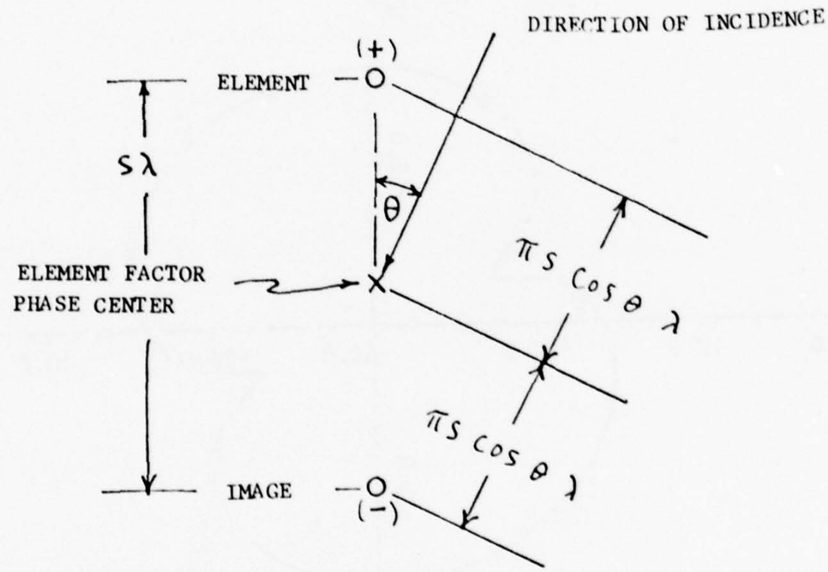
FIGURE H-2 ANTENNA GEOMETRY: ELEMENT AND IMAGE LOCATIONS

$\pm 2\pi \frac{r_s}{2} \cos\theta$ between each element and the midpoint between the elements. The total radiated electric field is the sum of the contributions due to the elements, and is

$$E(\theta) = \frac{1}{2j} \left[e^{j\pi r_s \cos\theta} - e^{-j\pi r_s \cos\theta} \right] \qquad \text{(H.2.8)}$$
$$= \sin\left[\pi r_s \cos\theta\right]$$

A one-half wavelength spacing $r_s = \frac{1}{2}$ achieves maximum forward gain for the single equivalent element. Figure H-4 shows the pattern for this spacing, plotted in db. The back lobe has the opposite phase of the front lobe, caused by the reversal in polarity of the image with respect to the element. A single equivalent element contributes as much flux in the back direction as it does in the forward direction. This is a result of the symmetry of the configuration and the assumption that the conducting cylinder is lossless.

In summary, a mathematical model of the array has been constructed by replacing each element in the array by a single equivalent radiator that represents the element and its image in the cylindrical conductor. Mutual coupling effects between the elements that might influence the radiation from the array by modifying its current distribution have been neglected. The radiation pattern for the equivalent element, calculated in (H.2.8), will be used in the following sections to compute the overall radiation pattern of the array within the limitations of the model that were described above.



ELEMENT FACTOR $\quad E(\theta) = \sin(\pi S \cos\theta)$

FIGURE H-3 GEOMETRY FOR CALCULATION OF ELEMENT FACTOR

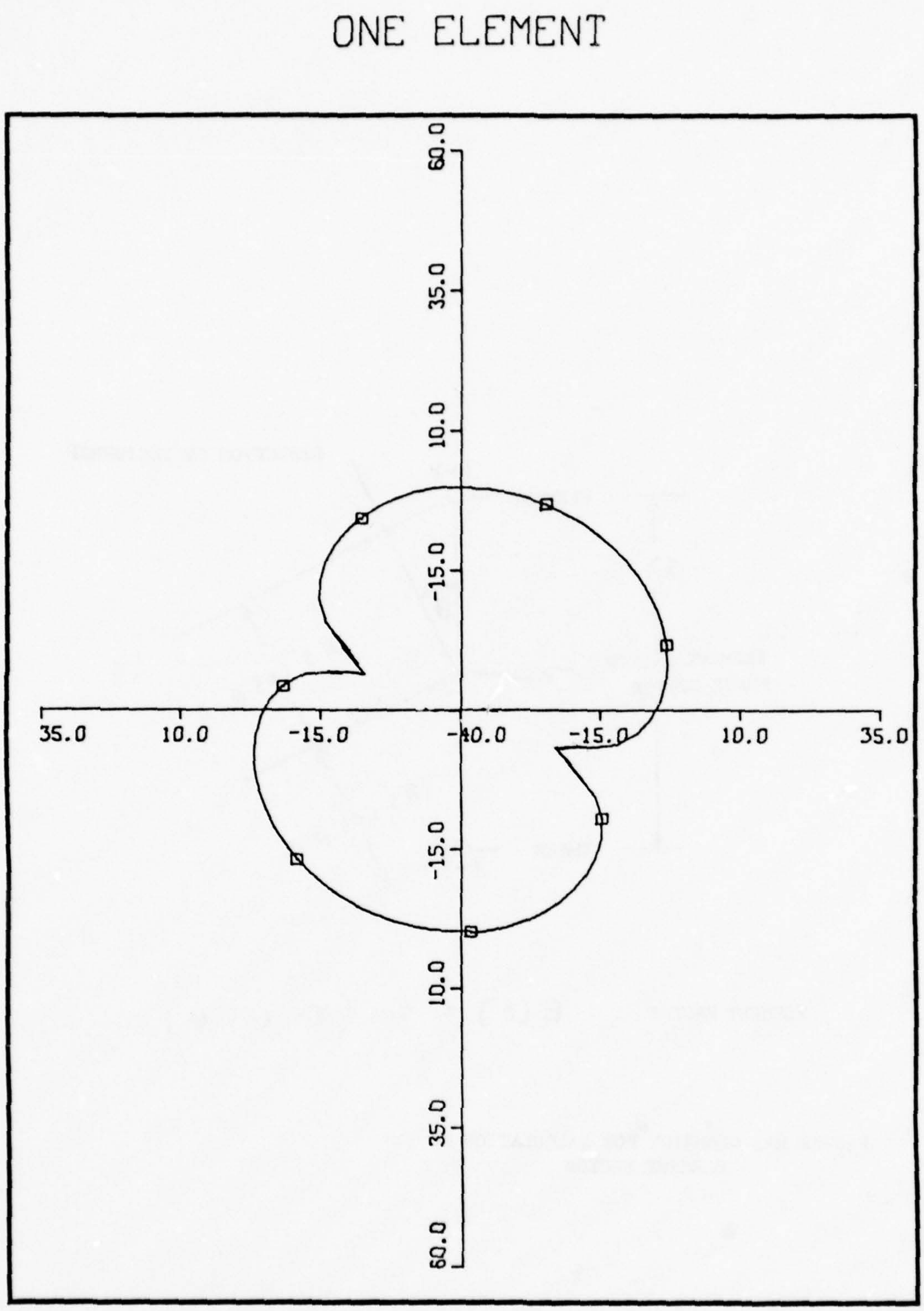


Figure H-4. Element Factor Pattern

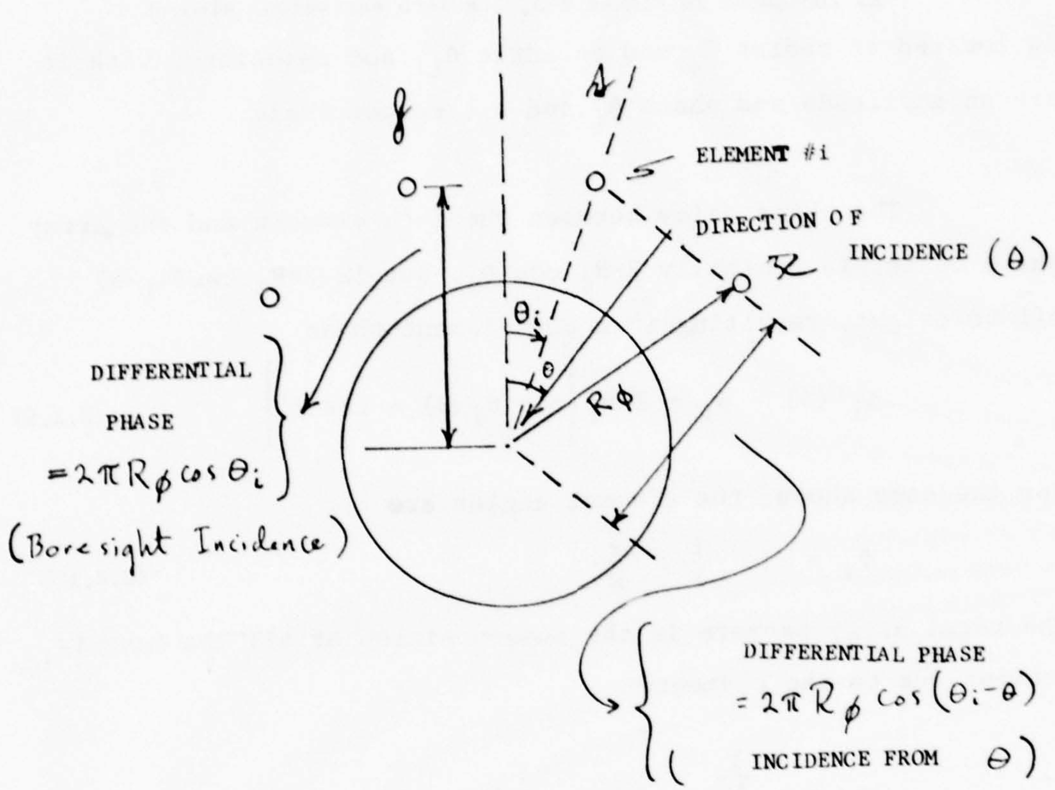


FIGURE H-5 GEOMETRY OF ARRAY PATTERN

H.2.2 Array Pattern

As indicated in Figure H-5, the i-th equivalent element is located at radius R_ϕ and an angle θ_i, and associated with it are an amplitude and phase A_i and ϕ_i, respectively.

The phase delay between the i-th element and the array phase center is nominally $2\pi R_\phi \cos \theta_i$, but is $2\pi R_\phi \cos(\theta_i - \theta)$ off boresight, resulting in a net element phase

$$\phi_i'(\theta) = \phi_i + 2\pi R_\phi \left[\cos(\theta_i - \theta) - \cos \theta_i\right] \qquad \text{(H.2.9)}$$

For the case shown, the element angles are

$$\theta_i = (i - \frac{1}{2}) \frac{2\pi}{N} \qquad \text{(H.2.10)}$$

The total array pattern is the superposition of all the contributions due to the elements:

$$P(\theta) = \sum_{i=1}^{N} E(\theta_i - \theta) A_i e^{j\phi'_i(\theta)} \qquad \text{(H.2.11)}$$

Because each element has its own factor (a rotated version of $E(\theta)$), it is not correct to compute the pattern by multiplying an array factor by an element factor, as is done when all elements have the identical factor.

Various patterns computed from (1) are shown in the subsequent analyses.

H.3 Application

The purpose of this section is to utilize the performance model of the array that was presented in((H.2.11) to evaluate various applications of the array to BCAS.

H.3.1 Monopulse Interrogation

In the active mode, the BCAS aircraft transmits an ATCRBS interrogation and determines both the ranges and altitudes of all replying aircraft. With an omnidirectional transmission, such as is used in the MITRE active BCAS system , no bearing information can be ascertained from the replies. However, a directional interrogation will elicit replies only from those aircraft in a restricted airspace volume; this both eliminates a certain amount of active garble and at least localizes the origin of each reply to the volume within the beam. More precise bearing information is obtained by monopulse in the receive mode, to be discussed shortly. The amount of directivity that can be achieved is limited most fundamentally by the aperture, which for reasons of practicality is on the order of 1λ - 2λ (30° - 60° BW). Further tightening of the reply region requires additional technique.

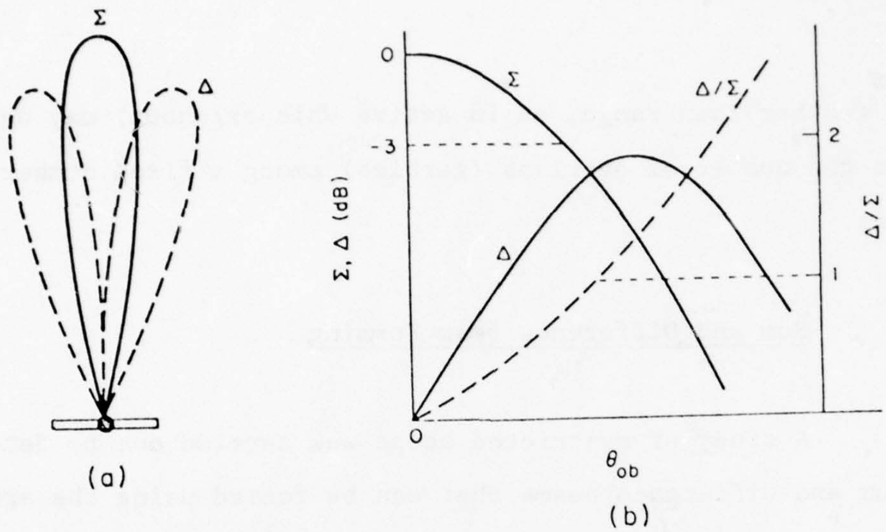
An ATCRBS interrogation from a ground radar consists of three pulses (P_1, P_2, and P_3) transmitted as follows. P_1 and P_3 are on the main beam; their spacing encodes the interrogation as Mode A (ID) or Mode C (altitude). The P_2 is

transmitted in between P_1 and P_2 on an omni antenna and the received P_1/P_2 ratio is used to test for SLS. The suppression rule is

$P_2 > P_1$	:	suppress
$P_2 < P_1 - 9dB$	:	respond
$P_1 - 9dB < P_2 < P_1$	:	varies with transponder

The angular sector within which aircraft will respond to an airborne BCAS interrogation can be controlled by transmitting the P_1 and P_3 pulses on the directive (Σ) beam and the P_2 on a Δ beam at increased power level. Figure 6 shows typical Σ and Δ beams. The Σ beam is even and fairly flat; the Δ beam has an odd characteristic with a null at boresight. An aircraft on boresight recieves no P_2 pulse and always replies. Off boresight, the received P_2 power increased rapidly and eventually covers the sum beam, suppressing all transponders. The greater the P_2/P_1 transmitted power ratio, the narrower the response region.

This narrowing of the response region has a threefold advantage. Active garble is reduced in proportion to the angular width of the region. This reduction brings more than a proportionate decrease in the effect of garble on bearing estimation, since the error contributed by a garbling aircraft is proportional to the angular separation between the target and the garbler, and this maximum separation is reduced by limiting the response region. Finally, the segregation of responses by



Σ SUM
Δ = DIFFERENCE
θ_{ob} = OFF-BORESIGHT ANGLE

Figure H-6. Typical Σ & Δ patterns

angle (rather than range, as in active Whisper/shout) may decrease the number of overlaps (garbles) among a fixed number of replies.

H.3.2 Sum and Difference Beam Forming

A study of restricted scope was carried out to determine the sum and difference beams that can be formed using the array. Beams were computed under the following conditions:

Boresight direction bisects two elements
Eight element array (N = 8)
Equal amplitudes ($A_i = 1$)
Elements phased for constructive interference at boresight
Element-image spacing = $\lambda/2$
Ground cylinder radius = $\lambda/2$

The element phases are adjusted to compensate for the element factor polarity. Figure H-7 shows polar dB plots of the resulting pattern. Several observations concerning these patterns can be made immediately.

1) Both the sum (Σ) and difference (Δ) patterns in Figure H-7 show both large sidelobes and a large backlobe.

2) The peak value of the Δ beam is 5dB below the Σ beam peak.

SUM BEAM

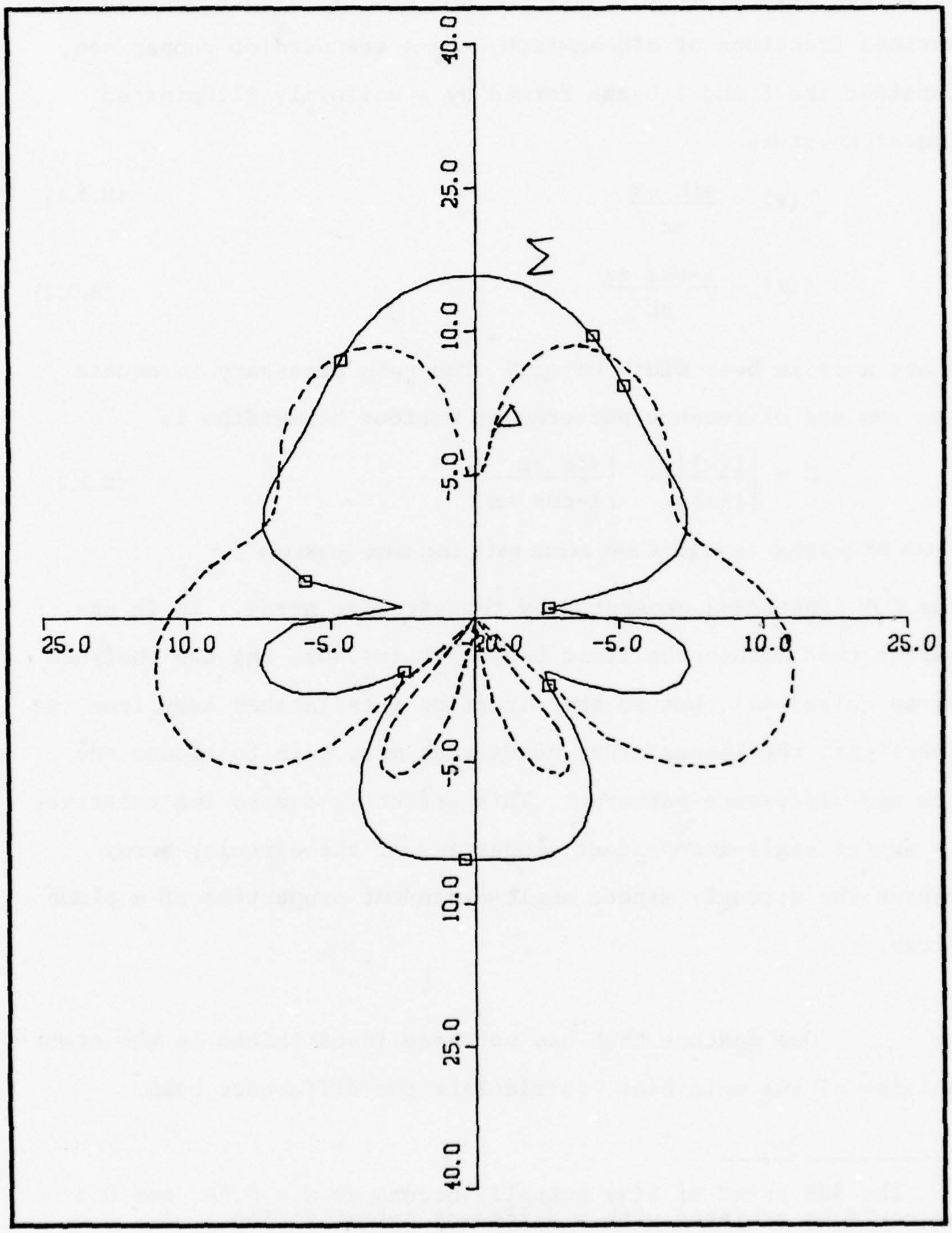


Figure H-7. Typical Σ and Δ Patterns

A question of interest is to determine the difference beam gain necessary to equate the sum and difference patterns at various fractions of a beamwidth. As a standard of comparison, consider the Σ and Δ beams formed by a uniformly illuminated linear aperture

$$\Sigma(x) = \frac{\sin \pi x}{\pi x} \tag{H.3.1}$$

$$\Delta(x) = \frac{1-\cos \pi x}{\pi x} \tag{H.3.2}$$

where x is in beam width units.* The gain necessary to equate the sum and difference patterns at various beamwidths is

$$G = \left|\frac{\Sigma(x)}{\Delta(x)}\right| = \left|\frac{\sin \pi x}{1-\cos \pi x}\right| , \tag{H.3.3}$$

which is plotted in Figure H-8 along with the same quantity for the $\Sigma + \Delta$ patterns generated by the circular array. It is apparent that within the first beamwidth ($x<.44$), the two analyses agree quite well, but as the direction gets farther away from the boresight, the linear array needs much more gain to equate the sum and difference patterns. This effect is due to the relatively aspect angle-independent properties of the circular array versus the strongly aspect angle-dependent properties of a plane array.

One feature that has not been investigated is the steerability of the main beam, particulary the difference beam.

---

*/ The 3dB point of $\Sigma(x)$ actually occurs at $x = 0.44$, not 0.5 as could be achieved with a different normalization.

The results presented in Figure H-7 are useful in appraising the overall approcah of monopulse interrogation. Considerable Δ-beam gain is required to narrow the response region to a small fraction of a beamwidth. A certain amount of gain requirement is tolerable at no penalty in forward sum beam EIRP because of the sum beam directivity. The maximum gain to be expected from the apertures under consideration is about 9dB. Thus any P_2/P_1 requirement less than 9dB still permits as much forward EIRP in the sum beam (P_1 and P_3) as would be obtained with an omni antenna. Greater ratios require a decrease in EIRP.

In view of this, the half-beamwidth sector appears to be the smallest practical beam splitting on interrogation. To achieve a quarter beam sector requires another 5dB, for example, which cuts the interrogation range down by 56%. Since even a modest amount of beam splitting requires a large power differential, alternative means of response region narrowing have been investigated.

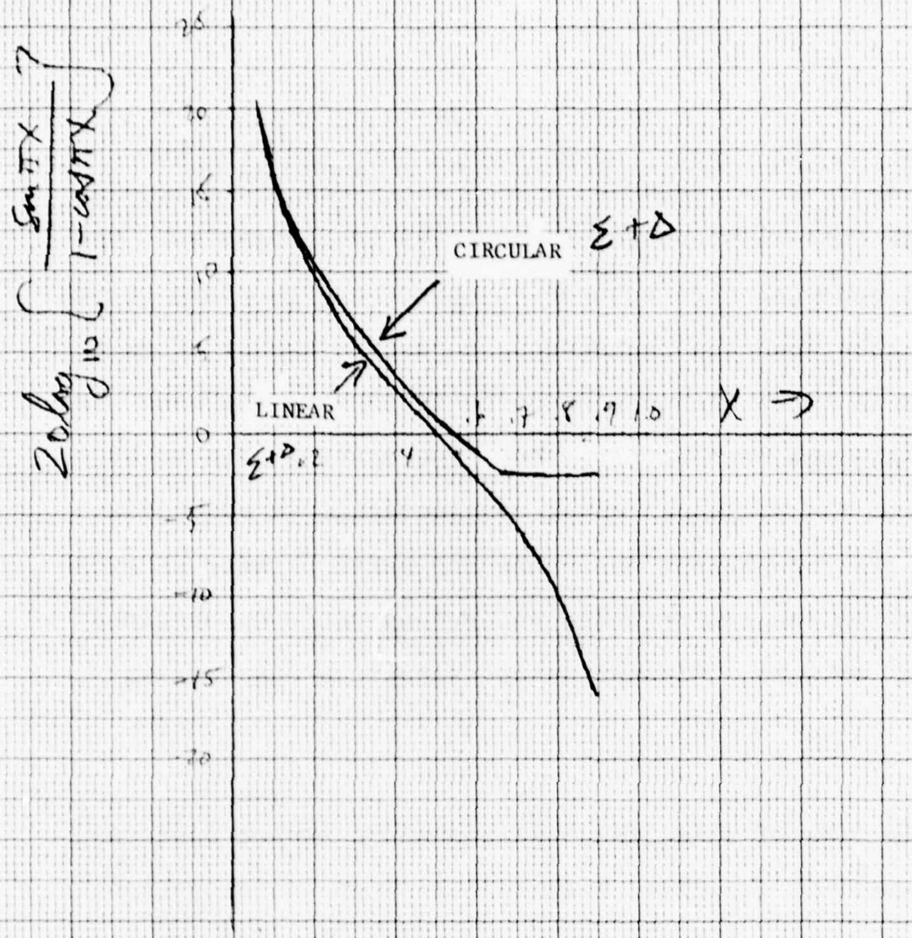


FIGURE H-8 GAIN REQUIRED FORCE SECTOR

Inverting of $\frac{\sin X}{X}$

H.4 Alternatives to Monopulse Interrogation

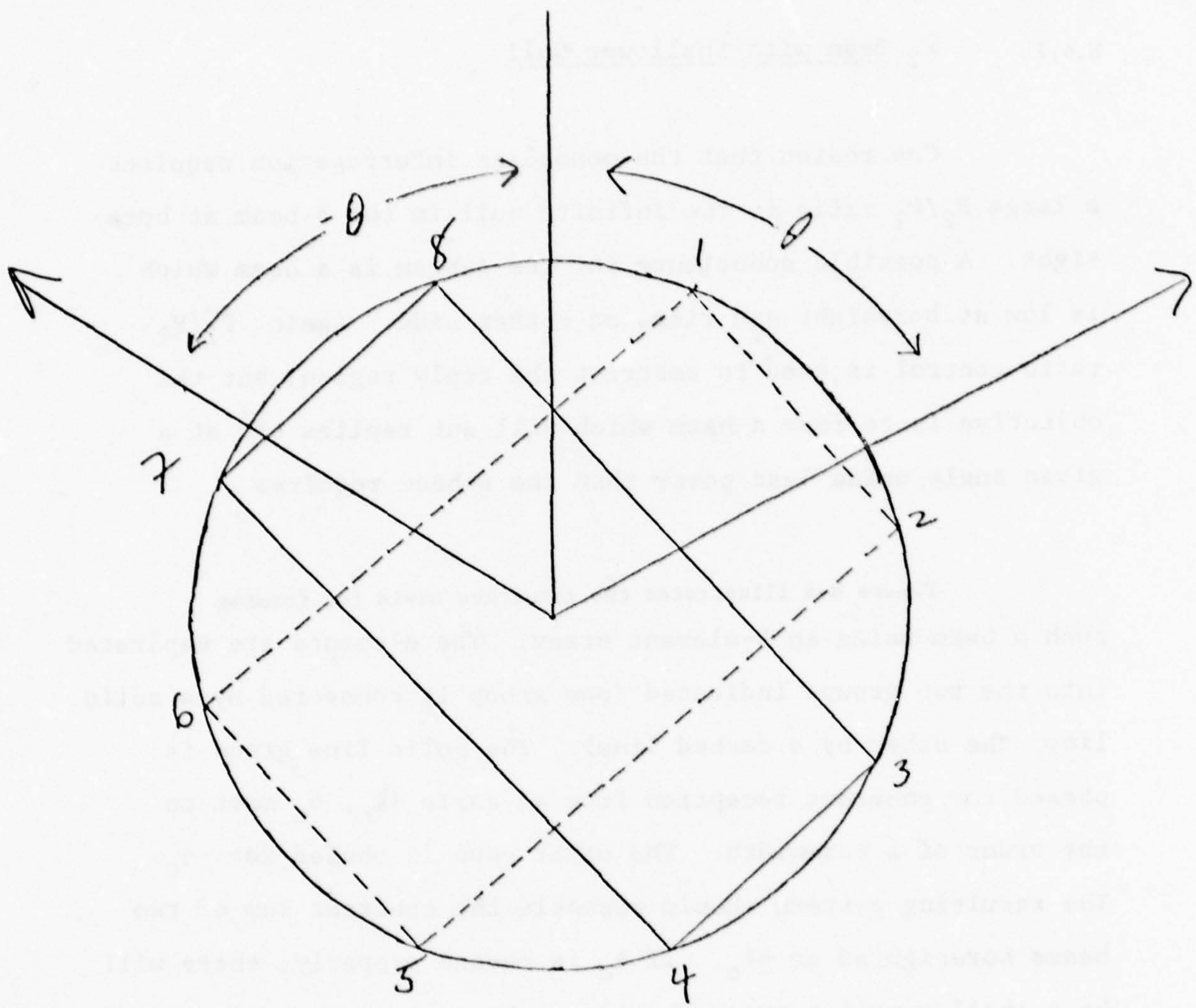
H.4.1 P_2 Beam with Shallower Null

One reason that the monopulse interrogation requires a large P_2/P_1 ratio is the infinite null in the Δ-beam at boresight. A possible substitute for the Δ-beam is a beam which is low at boresight and rises on either side. Again, P_2/P_1 ratio control is used to restrict the reply region, but the objective is to form a beam which will cut replies off at a given angle using less power than the Δ-beam requires.

Figure H-9 illustrates the intuitive basis for forming such a beam using an 8-element array. The elements are separated into the two groups indicated (one group is connected by a solid line, the other by a dashed line). The solid line group is phased for coherent reception from an angle $+\theta_o$; θ_o must on the order of a beamwidth. The other goup is phased for $-\theta_o$. The resulting pattern should resemble the coherent sum of two beams boresighted at $\pm\theta_o$. If θ_o is chosen properly, there will be a shallow null between the two peaks.

Figure's H-10 and H-11 show two patterns computed bv this technique. In each case the sum beam is superposed for comparison. In figure H-11, the subarry boresight angle is $\theta_o = 60^o$;

0 DEGREES



FIGUER #-9 BASIS FOR SHALLOW NULL STEERING

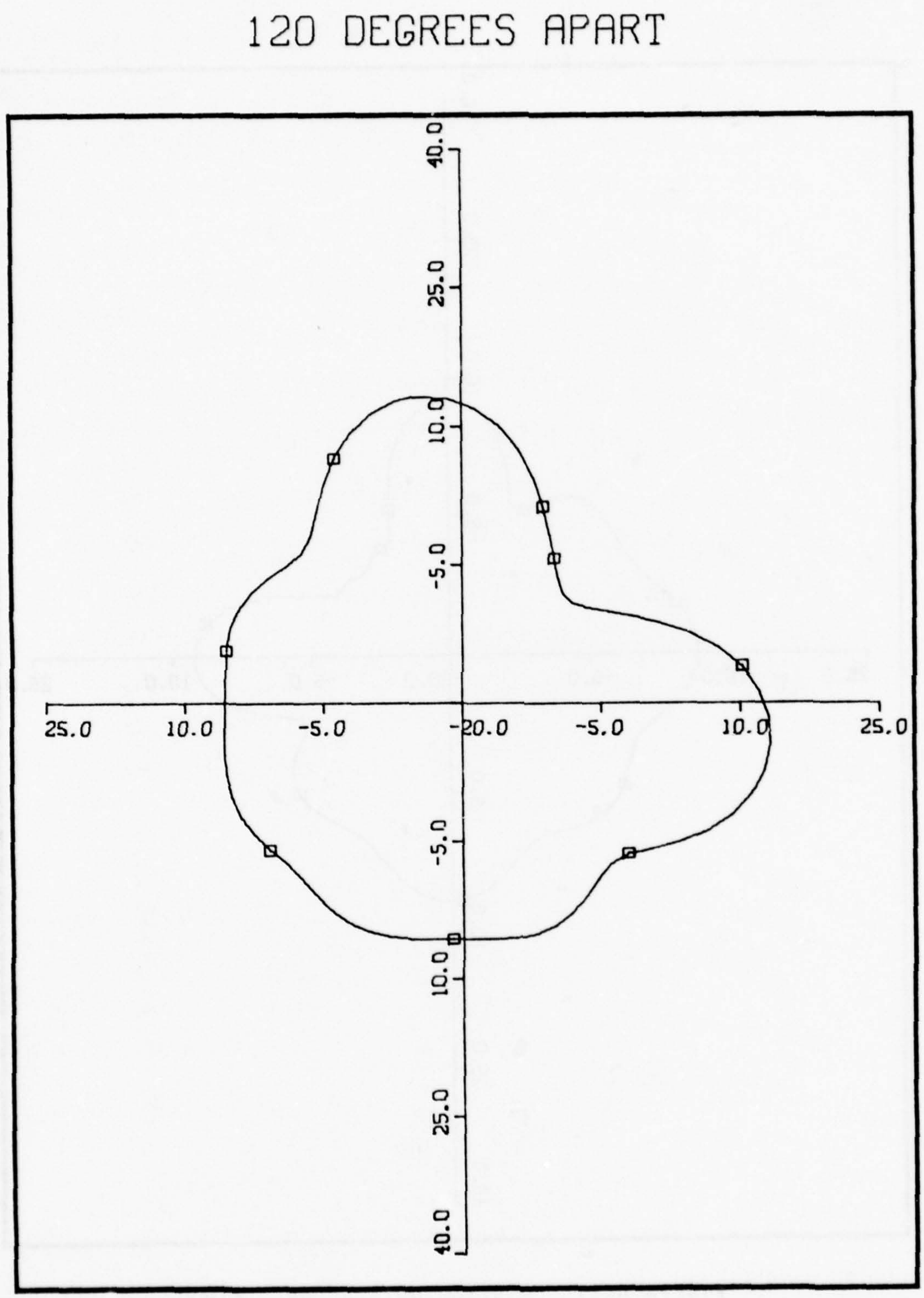


Figure H-10. Shallow Null Array σ = 60°

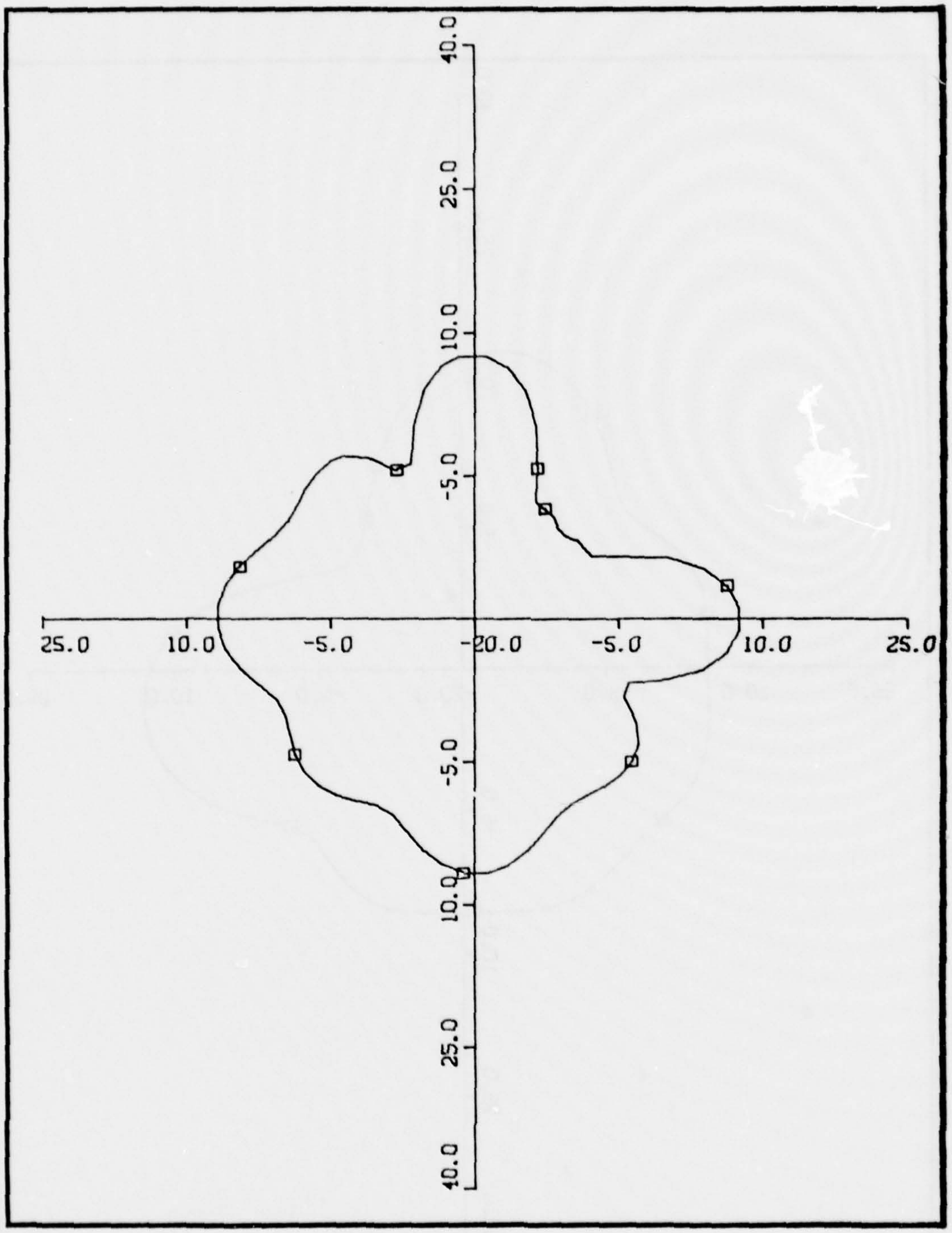


Figure H-11. Shallow Null Array σ = 45°

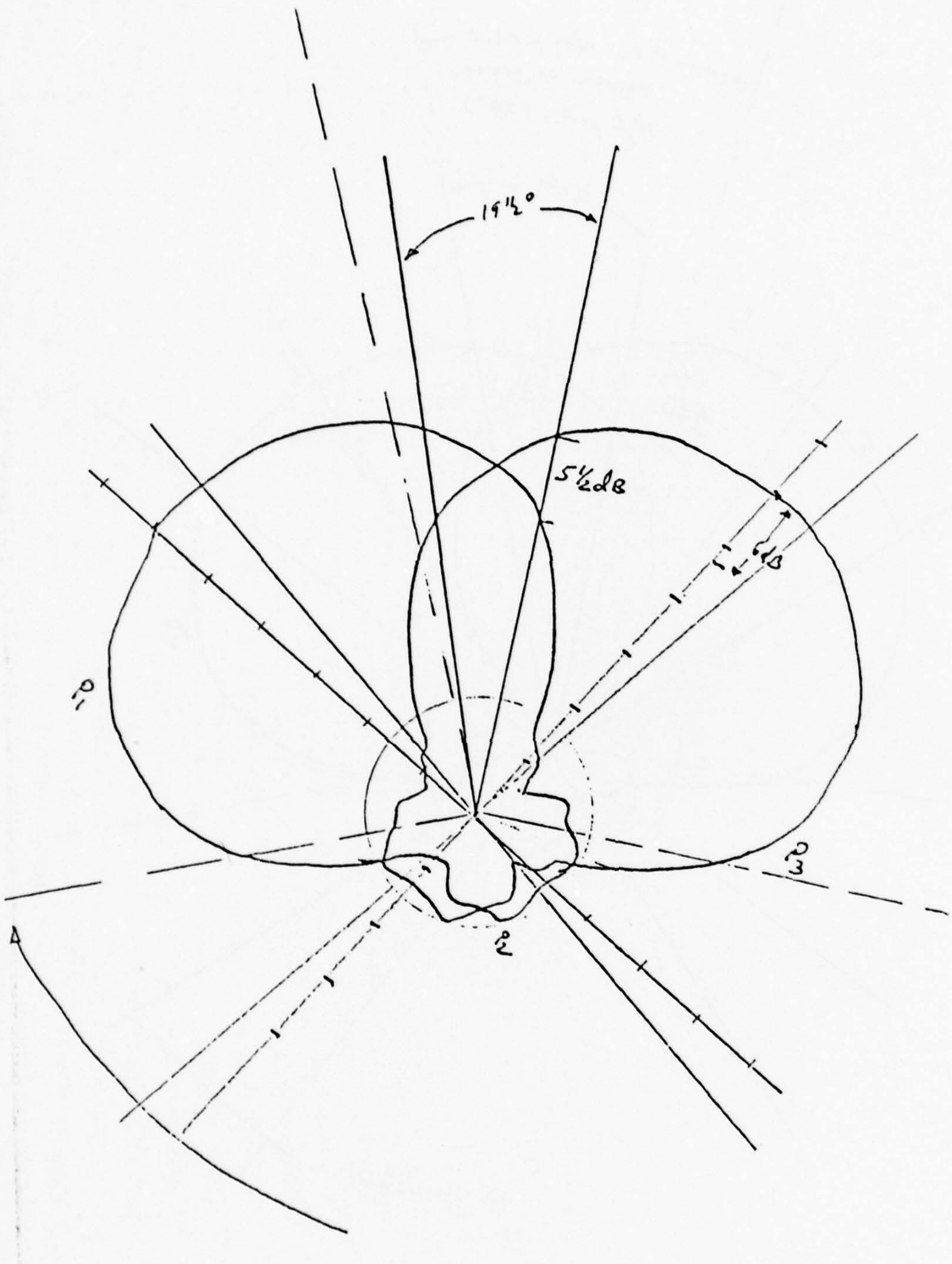


Figure H-12

$\frac{P_2}{P_1}$ = 15 dB. when P_2 transmitted on P_3 beam

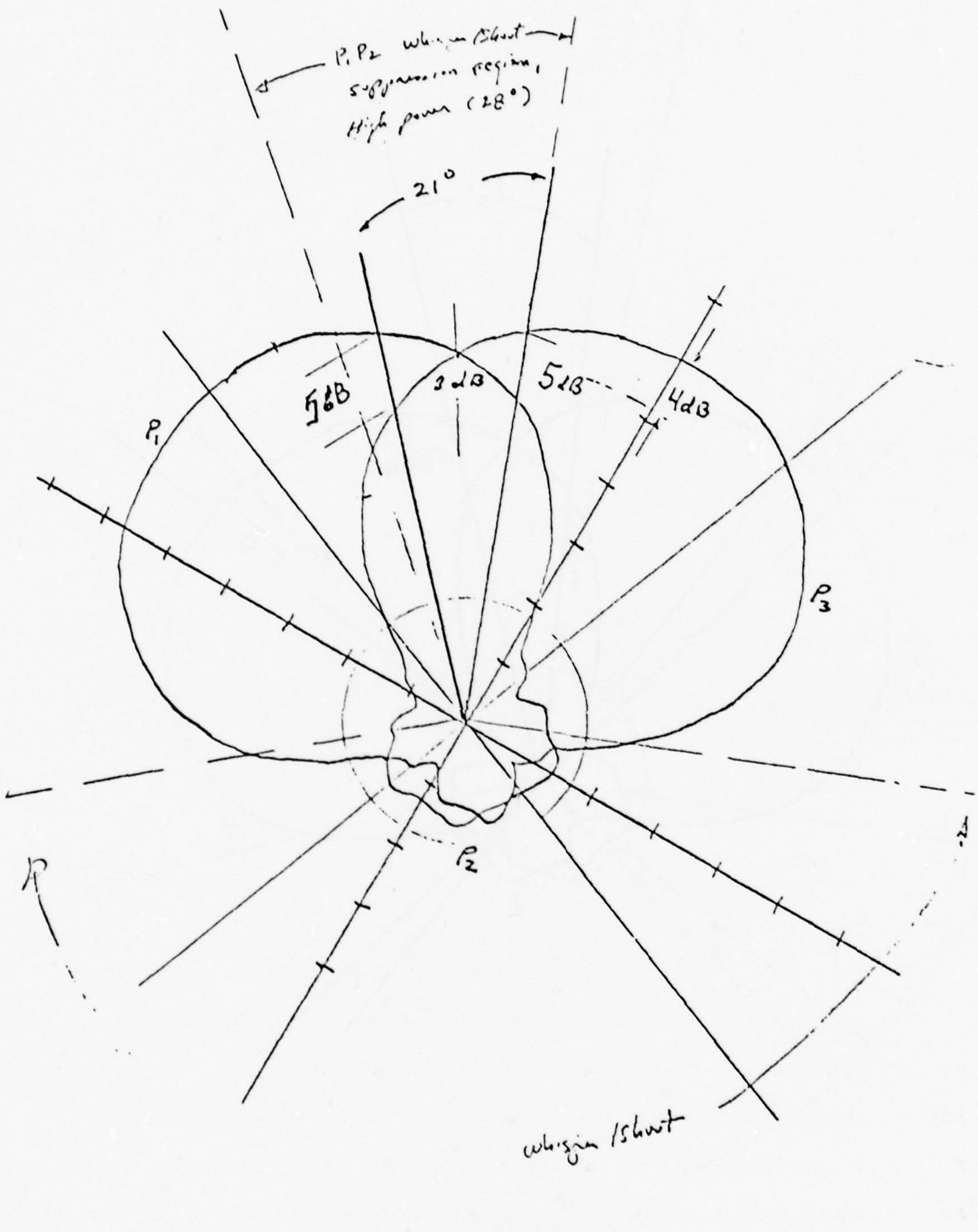


Figure H-13: $\frac{P_1}{P_2}$ = 16 db when P_2 goes out mP_3 beam

in Figure H-11, it is $\theta_0 = 45^{\circ}$. In each case the general pattern shape conforms qualitatively to the design goal in that there is a shallow null at the boresight. In each case shown, however, the null is still too deep to alleviate the problem. By boresighting the two subarrays closer to the main array boresight, a still shallower null could be obtained. It is felt that the basic technique will work once an appropriate subarray boresight is determined, and this topic will be pursued in subsequent study.

H.4.2 P_1 and P_3 on Separate Sum Beams

For a transponder to acknowledge that an interrogation has been received, it must among other things detect the presence of both a P_1 and P_3 pulse at one of the proper mode spacings. If the P_1 and P_3 pulses are transmitted on sum beams which are boresighted in different directions, then only in the region between them will there be sufficient energy on both for the transponder to declare an interrogation.

Figures H-12 and H-13 shows the idea for sum beam. It is assumed that the sector cutoff is the point 3dB below the beam intersection. Since the comparison here is on absolute levels, rather that relative levels (as in the P_1 P_2 Σ-Δ method), there is a wide range of variability in signal level relative to transponder MTL, and thus a corresponding variability in the location of the responding aircraft. This technique can, however, be used

in conjunction with a P_2 transmission of controlled level and beam pattern to introduce a measure of relative level control. This is illustrated in a later example.

In order to predict how the P_1 - P_3 technique would work with a beam having a sharper cutoff, the response sector is derived for a Gaussian beam as a function of the separation between the beams. Reference Figure H-14 for the following discussion.

The Gaussian pattern as a function of angle in 3dB beamwidth units (x) is

$$P(x) = 2^{-2x^2}$$

Assume the P_1 and P_3 beams are displaced by amount θ symmetrically around the boresight, i.e.,

$$P_1(x) = P(x+\theta)$$
$$P_3(x) = P(x-\theta)$$

The intersection is of course at x = 0, and at that point the beam amplitude is $P(\theta) = 2^{-2\theta^2}$, which is $12\theta^2$ dB below the peak. The point at which each beam is N dB down from that is found by solving

$$P(X+\theta) = 10^{-0.05N}\, P(\theta)$$

for x, which yields

$$x = \frac{1}{2\theta}\left[\frac{N}{12} + \theta^2\right]$$

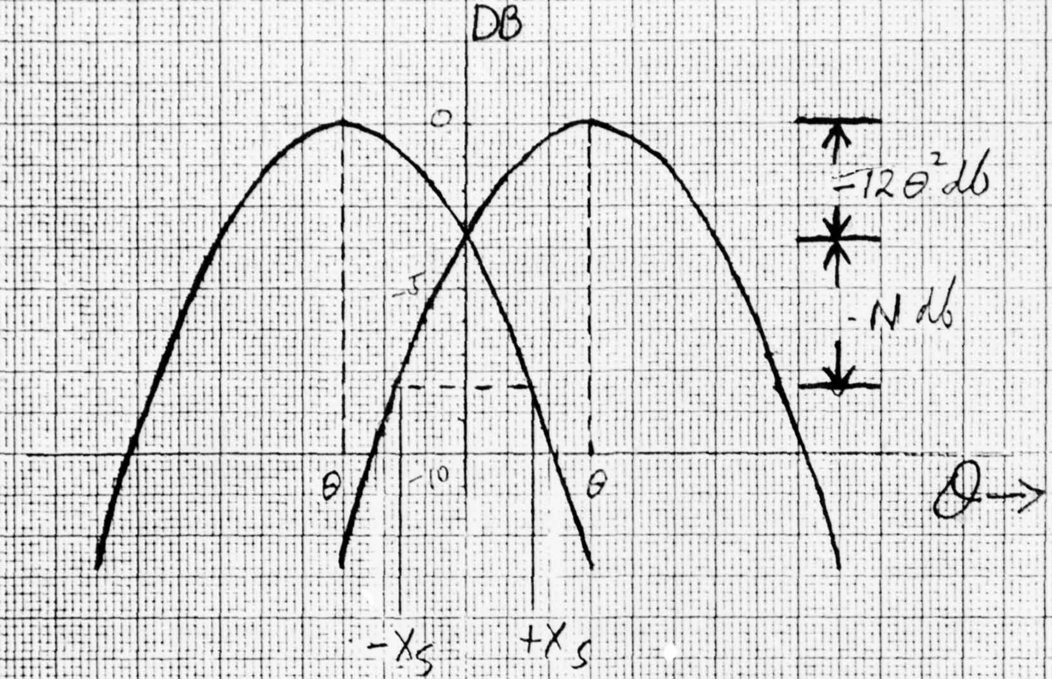


FIGURE 14 P_1 P_3 GAUSSIAN BEAMS

which can also be written as

$$x = \theta \left[\sqrt{1 + R} - 1 \right]$$

where R is

$$R = \frac{\text{beam crossing-to-MTL ratio (in dB)}}{\text{beam peak-to-beam crossing ratio (in dB)}}$$

$$= \frac{N}{12\theta^2}$$

The sector width, 2x, is plotted vs θ in Figure H-15 for the case in which MTL is 3dB below the beam crossing. The graph shows, for example, that by boresighting each beam 0.7 BW on either side of the desired boresight, a $\frac{1}{3}$ BW sector can be obtained (20° out of 60°).

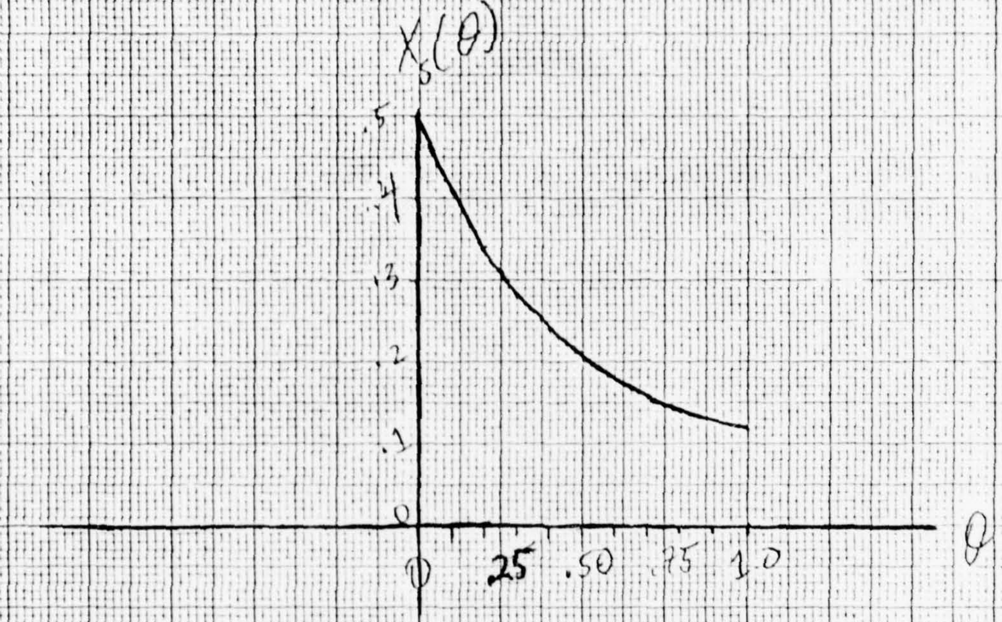


FIGURE H-15 SECTOR WIDTH X_s θ, FOR GAUSSION BEAMS.

REFERENCES

H.1. Ramo, S., Whinnery, J. R. and Van Duzer, T. Fields and Waves in Communications Electronics, Wiley, N.Y., (1967), P. 651.

APPENDIX I

BCAS Problems Solved via the Directional Antenna

BCAS is an area in which many problems of long standing have thus far evaded solution. Introduction of the directive antenna concept into BCAS provides an additional degree of freedom which both creates new problems and enables solution of old ones. Three such problems are considered in this appendix. In each case, the key to the solution is the directive antenna.

Section I.1 solves a very old BCAS problem: determination of North reference of an ATCRBS beam without the use of (i) a North reference pulse kit installed at the site, (ii) a radar-based transponder (RBX) installed at the site, or (iii) a multisite solution.

In Section I.2., a new problem is addressed. One very important application of the circular phased array is the ability to determine angle of arrival of a signal by off-boresight monopulse processing. In both active and passive modes, the accuracy of such measurements in the presence of interference (synchronous garble) is of concern. The combined effects of

limiting the region within which aircraft reply to less than a beamwidth (using a special interrogation technique) and monopulse processing on receive are derived in this section.

A problem which arose in the (omnidirectional) active BCAS experiments is the occurence of phantom targets generated by garbling of altitude replies from aircraft on the ground that have their transponders turned on. In a range/altitude system, phantoms cannot be detected with any certainty. The addition of directivity allowing measurement of bearing and bearing rate) opens many options for rapid and reliable detection of phantoms. Some of these are explored in Section 3.

I.1 Determination of North Reference of an ATCRBS Site

This appendix considers the problem of having a BCAS aircraft determine North passage reference of an ATCRBS beam which is not equipped with any special instrumentation for this purpose (e.g., North pulse kits or an RBX). The BCAS aircraft is equipped with a steerable directional phased array antenna which can employ monopulse techniques. The directive antenna is used to determine the direction to the site by measuring angle of arrival of the ATCRBS interrogations. Beam passage time at BCAS is measured by centermarking on the interrogations. Using a compass-derived heading, BCAS can infer time of North passage of the ATCRBS beam.

The primary analytical consideration here is the statistical characterization of the monopulse azimuth estimate; an associated link budget is included which allows us to compute the accuracy for an illustrative operational situation. Other system aspects discussed in this Appendix include a determination of the accuracy of the ATCRBS beam centermark, an examination of a typical BCAS situation which employs the above information, and the means for treating a specific singular situation that may occur.

I.1.1 Statistical Characterization of Azmiuth Estimate

The situation we consider here assumes the absence of all signals exclusive of the ATCRBS 1030 MHz interrrogation. Each interrogation consists of two 0.8 μs pulses appropriately spaced in time with N such pulse pairs available to the BCAS equipped aircraft per ATCRBS sweep (4 seconds). The quantity N is typically on the order of 16 to 32 and is a function of several system parameters. A specific example is considered later.

To proceed we first consider the azimuth estimate obtained by processing a single sum beam-difference beam monopulse pair. In accordance with [I.1] the mean of the azimuth estimate, $\hat{\theta}$, obtained from a single received sample is given by:

$$\hat{\theta} = \theta_s \left[1 - \exp\left(\frac{-A_s{}^2 K_\varepsilon{}^2}{\sigma^2}\right)\right] \tag{I.1}$$

where θ_s is the actual azimuth relative to the boresight direction and the argument of exp $(\cdot)$ is the negative of the SNR

in the sum beam. We see from (I-1) that the estimate is biased in the direction of the antenna boresight. For large SNR (e.g., > 10 dB), however, the bias is negligible. This, in fact, is the case of interest here.

The corresponding variance of $\hat{\theta}$ is also given in [1]. The result is

$$\mathrm{var}\ (\hat{\theta}) \simeq \left[\frac{\sigma^2}{2K_\varepsilon{}^2 A_s{}^2}\right] \left[\frac{1+k^2\theta_s{}^2}{k^2}\right] \qquad \text{(I-2)}$$

where

$$k = K_\Delta / K_\varepsilon \qquad \text{(I-3)}$$

is the slope of the normalized difference pattern.

Since it is possible that the accuracy of I-2 will not be sufficient, it may be desirable to form an azimuth estimate based on multiple independent observations. This would consist of forming the sample mean

$$\hat{\theta} = \frac{1}{N} \sum_{i=1}^{N} \hat{\theta}_i \qquad \text{(I-4)}$$

where $\hat{\theta}_i$ is the azimuth estimate based on the ith observation. Under such circumstances and for high SNR the mean of $\hat{\theta}$ is unbiased and the variance becomes,

$$\operatorname{var}(\hat{\theta}) = \frac{1}{N^2} \left[\frac{\sigma^2}{2K_\varepsilon{}^2 A_s{}^2}\right] \left[\frac{1+k^2\theta_s{}^2}{k^2}\right] \sum_{i=1}^{N} P_i \quad \text{(I-5)}$$

where $K_\varepsilon{}^2 A_s{}^2/\sigma^2$ now represents the SNR corresponding to the peak of the ATCRBS mainlobe beam while the set of $\{P_i\}$ account for the SNR variations due to the ATCRBS antenna pattern.

To provide some feel for the accuracy achievable, the situation considered here is one in which the BCAS aircraft is equipped with a directional antenna having a 45° 3 dB beamwidth. A link budget for transmissions from the ATCRBS site to the aircraft is contained in Table I-1.

The power budget of Table I-1 assumes the ATCRBS mainlobe beam to be at its 3dB point relative to the BCAS aircraft. In reality the ATCRBS beam is sweeping at a rate of one 360° sweep each 4 seconds. This fact, combined with a 350-450 ATCRBS interrogation pulse-pair repetition rate, implies that numerous pulse pairs at varying ATCRBS beam azimuths will be available to the BCAS receiver. Thus, to account for the varying ATCRBS mainlobe gain, the following Gaussian antenna pattern is assumed:

Table I-1:

LINK BUDGET - ATCRBS-TO-BCAS A/C (100 NMI RANGE)

Transmitter Power	-	24.8 dBW
ATCRBS Antenna Gain	-	19.5 dB
ATCRBS Cable Loss	-	-2.0 dB
Off Center Beam Loss	-	-3.0 dB
Path Loss (100 Miles)	-	-138.0 dB
BCAS A/C Antenna Gain	-	8.0 dB
BCAS A/C Cable Loss	-	-3.0 dB
Received Power	-	-93.7 dBW
Received Energy (.8 μs Bit)	-	-154.7 dBJ
Receiver Noise Power Density	-	-197.0 dBJ (7 dB NF)
Signal Energy-To-Noise Spectral Density, E/N_o	-	42.3 dB
BCAS A/C Receiver Implementation Loss	-	-3.0 dB
Net E/N_o	-	39.3 dB

$$P(\theta) = e^{-\ln 2(\theta/1.65)^2} \qquad \text{(I-6)}$$

where the exponent is based on the fact that the 3dB point occurs at $\theta = \pm 1.65°$.

To proceed, the number of pulse pairs available to the BCAS aircraft must now be determined. By virtue of the ATCRBS sidelobe suppression (SLS) capability, the BCAS aircraft should receive pulse pairs for ATCRBS mainlobe gain values that are as much as 9dB below that of the centermark.* For simplicity, the conservative situation considered here is one aircraft receiving ATCRBS pulse pairs between the -5 dB points on the beam. If an ATCRBS PRF of 360 interrogations/second (nearly the minimum PRF used), is further assumed in conjunction with the 4 second sweep period, the conclusion arrived at is that pulse pairs are 0.25° apart and that approximately 16 pulse pairs will be available to the BCAS aircraft in the ATCRBS 5 dB beamwidth. Employment of the beam pattern of (I-6), in conjunction with the availability of 15 pulse pairs**, the following table of $P(\theta_i) = P_i$ values is obtained:

*/ Considerations relative to centermark determination are treated later in this Appendix.

**/15 pulse pairs are used here to maintain symmetry about the centermark.

θ_i (degrees)	P_i (dB)	θ_i (degrees)	P_i (dB)
0	0	$\pm$ 1	-1.1
$\pm$ 1/4	-.1	$\pm$ 5/4	-1.7
$\pm$ 1/2	-.3	$\pm$ 3/2	-2.5
$\pm$ 3/4	-.6	$\pm$ 7/4	-3.4

To obtain the final answer via I-5 the value of the normalized slope parameter k must be ascertained from appropriate antenna patterns. Employment of the patterns of Appendix H yields

$$k \approx .01 \tag{I-7}$$

Finally, use of (I-5) and the fact that N = 30 (15 pulse pairs) leads to the standard deviation of $\hat{\theta}$ being given by

$$\sigma(\hat{\theta}) \approx .1° \tag{I-8}$$

Our conclusion for this illustrative situation therefore is that the azimuth of the ATCRBS site may be determined to a one standard deviation accuracy of approximately 0.1°!

*/ Since the SNR here is very high, $\hat{\theta}$ is clearly unbiased.

I.1.2 ATCRBS Centermark and North Passage Time Determination

Conversion of site azimuth to North reference involves a BCAS aircraft determination of the ATCRBS centermark. This is required in order to determine the time at which the center of the ATCRBS beam passes through some desired direction (e.g., north). Such information is necessary if a BCAS aircraft is to take advantage of the ATCRBS site in locating a target (following subsection).

The BCAS aircraft can centermark the ATCRBS beam using the sliding window detector algorithm employed by the ATCRBS reply processor. In fact, the situation is much simpler here because the interrogation round reliability is much higher that the reply round relieability. Centermark is the average of the leading and trailing mainbeam interrogation arrival times. Due to the ATCRBS SLS capability and the high SNRs that are dealt with, all pulse pairs assumed arriving above the SLS threshold are assumed to be detected by the BCAS aircraft. Now, due to the ATCRBS pulse-pair repitition rate (e.g., 350-450 per second), each pulse pair will be separated by a fraction of a degree. For example, in the above situation, this separation was shown to be 1/4°. Because this "phase quantization", and the fact that the pulse pairs and beam sweep rate are not synchronized, it is assumed that the centermark uncertainty can be modelled as a uniformly distributed random variable, θ_c, in the range (-1/4°, +1/4°). The corresponding

standard deviation then becomes*

$$\sigma(\theta_c) = \frac{1/4}{\sqrt{3}} \simeq .15° \qquad \text{(I-9)}$$

In computing the time at which the ATCRBS beam passes North, both centermark and azimuth information must be employed. Thus, combining (I-8) and (I-9) we conclude that the to rms angular error, $\sigma(a)$ is

$$\sigma(a) = \sqrt{(.1)^2 + (.15)^2} \simeq .18° \qquad \text{(I-10)}$$

The corresponding rms <u>time</u> uncertainty, $\sigma(t)$, in ATCRBS North passage is then based on the sweep rate - i.e., 360° in 4 seconds. We thus obtain

$$\sigma(t) \simeq 2 \text{ ms} \qquad \text{(I-11)}$$

Thus, with one standard deviation accuracy we can determine ATCRBS North passage time to within ±2 ms.

---

*/ Since SLS is not perfect a pulse pair at the beginning or end may either be added or dropped, thus biasing the centermark determination. For the present situation the bias would be 1/8°

I.1.3 Application of Azimuth and Centermark Determination

The situation of interest is described in Figure I-1.

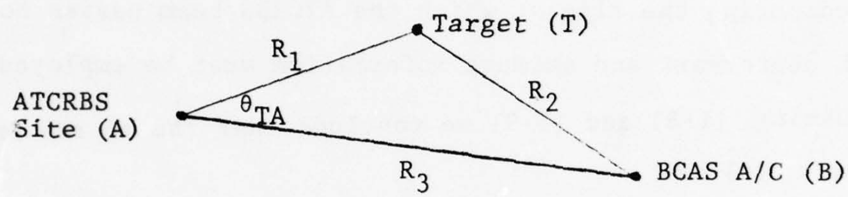


Figure I-1: Single Site Measurement Geometry

Once the BCAS aircraft (B) has determined the ATCRBS beam centermark and the relative azimuth of the site, B will also know the times at which the centermark passes through any relative direction. The word "relative" is employed here since B's computations are based on its heading information which may be somewhat in error. In addition to heading error, further errors would be due to those described in the previous two subsections.

The BCAS determination of the Target's relative position consists of three elements. First, B listens to T's response to an ATCRBS interrogation and uses its knowledge

of ATCRBS interrogation times (which are separated by approximately 2.5 ms), together with the fact that T is within 20 miles, to determine $\Delta R=R_1+R_2-R_3$. Next, the angle θ_{TA} is measured by determining the time difference between centermark incidences at T and B. Finally, the distance R_2 is computed via active BCAS interrogation. These three pieces of information uniquely define the triangle of Figure I-1, which then allows B to determine the relative position of T.

I.1.4 Impact of Heading Error

It is clear that B's determination of T's position is affected by the errors of the previous two subsections. On the other hand, the impace of B's uncertainty of its own heading has not been considered thus far. If the above development is examined, the conclusion reached is that only the θ_{TA} and ΔR computations depend on heading information. In other words, the time at which the ATCRBS centermark passes through a prescribed direction (e.g., North) is based on the accuracy of B's North determination. It is observed, however, that B's heading never enters in an absolute way; instead, both ΔR and θ_{TA} are determined via time difference measurements. Thus, any error

in B's heading will cancel. The conclusion reached then is that any bias* in B's heading information does not impact measurement of T's position.

I.1.5 Impact of North Reference Measurement on BCAS Function

In the BCAS mode to which the present discussion is pertinent, the only site visible to BCAS is the ATCRBS site in question. Thus BCAS, although DABS-equipped, must reply to ATCRBS. There is the possibility that in the process of replying, some target replies might be missed, since obth are at the standard ATCRBS reply frequency, 1090 MHz.

As is discussed in the concept description, the replies which would be missed would be those having less than 20.3 μs (the reply duration) differential time of arrival. These are in-beam replies from aircraft which lie between BCAS and the site. But this case of colinearty is exactly the singularity of the single-site solution, and it is solved in this case just as in the others, by active interrogation. Active interrogation, timed to occur when the main beam is away from the targets in the singularity, provides full track on those targets, and hence there is no loss in the failure to passively detect their ATCRBS replies.

*/ This bias may be time varying due to magnetic North deviations. The impact of magnetic deviations is not included in the present consideration, but an overview of this general problem is presented in Appendix G.

I.2. Monopulse Bearing Estimation Accuracy in Garble

The effects of interference on the accuracy of off-boresight monopulse have been studied in various radar contexts. The work of greatest relevance here was performed in the DABS program at M.I.T. Lincoln Laboratory. In a series of memoranda, (References I-1 and I-2) have found the effects of both ATCRBS interference and DABS multipath on DABS azimuth estimation. Their results are useful as starting points for solving the corresponding problem in BCAS.

I.2.1 Single Garble Results

The multipath results appear to be most applicable here in that they correspond to an interference which (i) arrives simultaneously with the desired signal, and (ii) is perfectly correlated with it. Any other type of interference having the same power and direction of arrival as the multipath return will be less correlated and should have a smaller effect. Thus the use of multipath results is conservative in that it seems to overbound the error.

Approaches of varying complexity have been taken in analyzing this problem. One that appears to be satisfactory for the present problem in this. A monopulse angle estimate is made on a target return in the standard way, by estimating the signal content in a sum (Σ) and difference (Δ) beam and inverting the monopulse $\Delta(\theta)/\Sigma(\theta)$ curve. It is assumed here

that the target and any garbling aircraft are located close enough to boresight that the Δ beam is approximately linear. This assumption is quite reasonable here since the replies to be measured were elicited by some active technique that restricts the reply region to be a fraction (e.g., $< \frac{1}{2}$) of a beamwidth.

The following definitions are used:

θ_s = target signal bearing

θ_I = garble signal bearing

ϕ = RF phase difference between target reply and garble

ρ_o = garble amplitude/target amplitude

The effective strength of the garble signal is

$$\rho = \rho_o \frac{\Sigma(\theta_I)}{\Sigma(\theta_s)} \qquad \text{(I-12)}$$

i.e., there is some sum beam attenuation when the target is near boresight and the garble near the edge. When the garble is closer in than the target, there is magnification. And in any case, the value of ρ should further be attenuated by a correlation factor, as described earlier

In terms of these quantities, the monopulse angle estimate can be shown to be [I-1]

$$\hat{\theta} = \frac{\theta_s + (\theta_s + \theta_I)\,\rho\cos\phi + \rho^2\theta_I}{1 + 2\rho\cos\phi + \rho^2} \qquad \text{(I-13)}$$

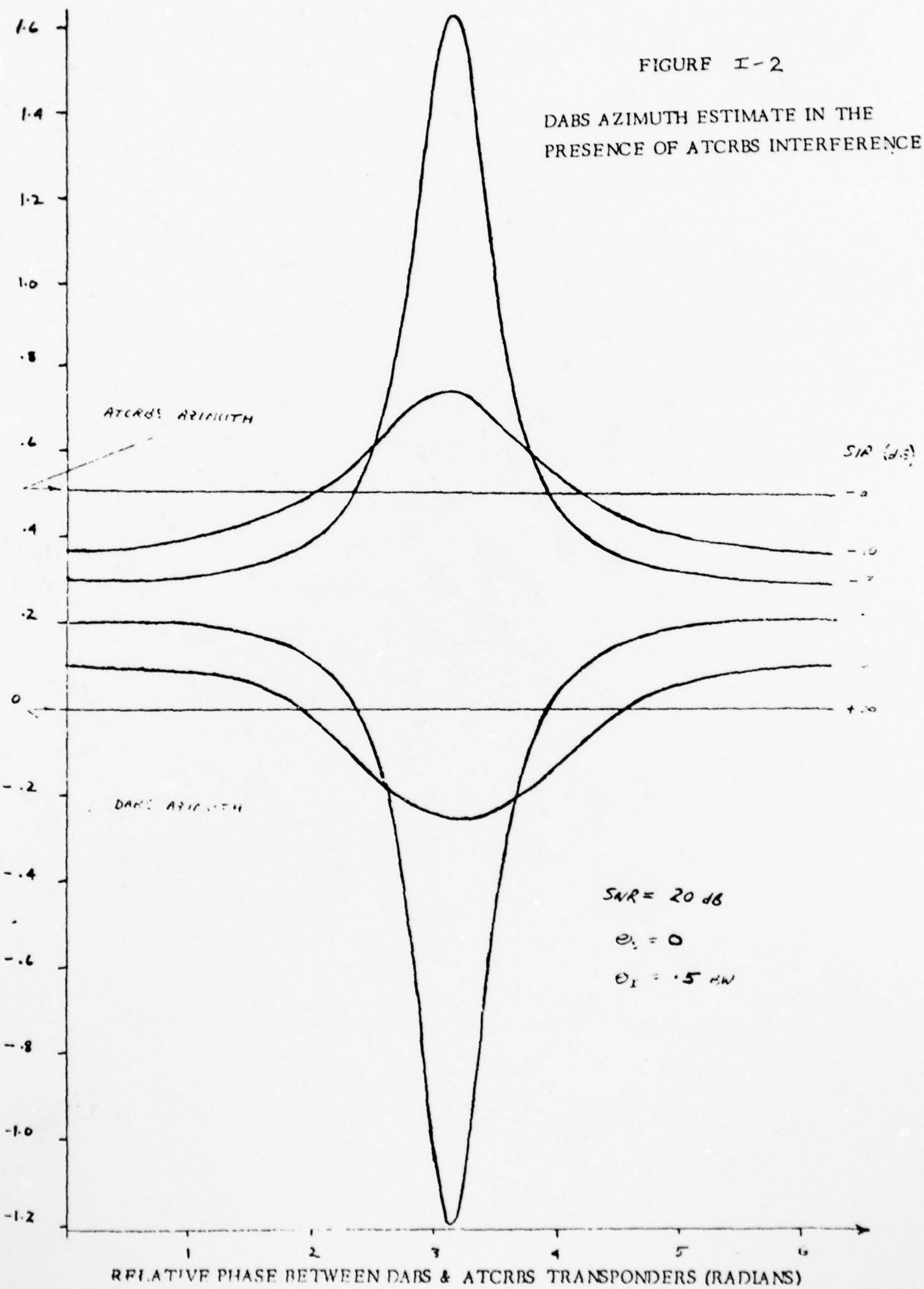


FIGURE I-2
DABS AZIMUTH ESTIMATE IN THE PRESENCE OF ATCRBS INTERFERENCE
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
-1.2
ATCRBS AZIMUTH
DABS AZIMUTH
SIR (dB)
SNR = 20 dB
1
2
3
4
5
6
RELATIVE PHASE BETWEEN DABS & ATCRBS TRANSPONDERS (RADIANS)

Equivalently, the error is

$$\varepsilon = \hat{\theta} - \theta_s = \rho(\theta_I - \theta_s)\left[\frac{\cos\phi + \rho}{1 + 2\rho\cos\phi + \rho^2}\right] \tag{I-14}$$

which can be written

$$\varepsilon = K(\rho,\phi)(\theta_I - \theta_s) \tag{I-15}$$

It is instructive to look at various values of the coefficient $K(\rho,\phi)$ vs ϕ

$$K(\rho,0) = \frac{\rho}{1+\rho} \qquad \text{(I-16) a}$$

$$K(\rho,\tfrac{\pi}{2}) = \frac{\rho^2}{1+\rho^2}$$

$$K(\rho,\pi) = \frac{-\rho}{1-\rho} \quad \text{(worst case)} \qquad \text{c}$$

For values of ρ near 1, the worst case peak error can be quite large. However, (16c) is not a very good indicator of performance, since (i) the error peak is very narrow in phase, and therefore quite unlikely and (ii), the large errors associated with worst case phase can be truncated considerably because they will indicate angle estimates which lie outside the known reply region. Figure I-2, taken from (Reference I-1), shows the behavior described above.

More meaningful measures for the case of garble performance are the bias and rms errors averaged over both phase and angular locations, θ_s and θ_I. The averages over phase are evaluated in detail in Section 2.3 of this Appendix. What is shown there is that the phase bias is zero unless the garble exceeds the target strength, in which case the bias is $\theta_I - \theta_s$ (i.e., the expected value of the estimate is the azimuth of the interference).

In summary

$$E_{\phi}(\theta) = \begin{cases} \theta_s & : \quad \rho<1 \\ \theta_I & : \quad \rho>1 \end{cases} \tag{I-17}$$

or

$$E_{\rho}(\varepsilon) = \begin{cases} o & : \quad \rho<1 \\ \theta_I-\theta_s & : \quad \rho>1 \end{cases} \tag{I-18}$$

The error variance over phase is also evaluated in Section 2.3. When $\rho<1$, the case of primary interest, we find

$$\sigma_{\phi}{}^2\ (\varepsilon) = \frac{\rho}{2(1-\rho^2)}\ (\theta_I-\theta_s)^2 \tag{I-19}$$

Both the target and interferer can be located anywhere within the response region. Assume that the target and interferer azimuths are independent random variables uniformly distributed over $(-\theta_m, \theta_m)$, where θ_m is the maximum off-bore-sight reply angle; then (see Section 2.3)

$$E_{\theta_I,\ \theta_s}\left[(\theta_I - \theta_s)^2\right] = \frac{2}{3}\,\theta_m^2 \tag{I-20}$$

which makes the overall rms error equal

$$\sigma_{\rho,\theta_I\ \theta_s}(\varepsilon) = \frac{\rho}{\sqrt{1-\rho^2}}\ \frac{\theta_m}{\sqrt{3}} \tag{I-21}$$

I.2.2 Multiple Garble Results

Let G_o represent the number of active garbles which would result from an omnidirectional active interrogation. Assuming uniform angular distribution of garble, the number of garbles within the beamwidth (BW) is

$$G_{BW} = G_o\left(\frac{BW}{360°}\right) \tag{I-22}$$

If the reply region is restricted to a fraction α of the BW, then G_{BW} is further reduced proportionately:

$$G_{\alpha_{BW}} = \alpha G_{BW} \tag{I-23}$$

We assume that each interferer contributes equally to the mean squared error, i.e., that the total rms error is proportional to the square root of the number of garbles.

The maximum reply sector is bounded by $\pm\,\theta_m = \pm\,\alpha/2$, which allows us to combine all the above into one error formula Since we have been dealing with error in BW units, the expression must be multiplied by BW° to get error in degrees

$$\sigma(\varepsilon)\Big|_{deg} = \frac{\rho}{\sqrt{1-\rho^2}}\;\frac{1}{2\sqrt{3}}\;\frac{\sqrt{G_o}}{\sqrt{360}}\;(\alpha BW^\circ)^{3/2}$$

$$= 104^\circ\left(\frac{\rho}{\sqrt{1-\rho^2}}\right)\sqrt{G_o}\left(\frac{\alpha BW^\circ}{360^\circ}\right)^{3/2} \tag{I-24}$$

Note that the error increases as sector width to the $^3/_2$ power. This is because the error per garble increases linearly with sector width, while the effect of the number of garble errors goes up with the square root of the sector width.

Angular dependence on ρ has been left out of the calculation, since it is slight (especially for a sector which is narrow compared to the BW) and in any event the absolute levels are difficult to predict because of power level variations due to the transponders, range, and signal-garble correlation. For an average level of $\rho = -3$ dB, the signal

strength term in (24) is unity. Thus we shall use the result

$$\sigma(\epsilon)\Big|_{deg} = 104° \sqrt{G_o} \left(\frac{\alpha BW°}{360°}\right)^{3/2} \qquad \text{(I-25)}$$

Figure I-3 shows a plot of error versus sector size for a very dense environment (LA 1985) in which it is assumed that as many as 80 garbles may be present omnidirectionally.

No editing of anomalously large estimates has been included in the derivation of the above error formula. The need for this in heavy garble environments is evident from the figure. Note that for sector widths greater than 13.5°, the rms error exceeds half the sector width, which is unnecessarily large. Even an "ignorant" estimator that assumes each reply to be located on boresight would make a smaller rms error.

In general, there is a relationship between the garble level and sector size which will tell whether estimates can be ascertained to any finer resolution level than the sector width. Equation (I-25) is used to find that relationship by calculating the maximum sector width for which the rms error equals half the width. Letting θ_s represent the sector width, solve

$$104 \sqrt{G_o} \left(\frac{\theta_s}{360}\right)^{3/2} \leq \frac{\theta_s}{2} \qquad \text{(I-26)}$$

for θ_s and get

$$\theta_s \leq \frac{1078}{G_o} \qquad \text{(I-27)}$$

Thus for example, according to (I-27), targets cannot be resolved within a 20° sector if the omni garble count exceeds 54.

If sector limiting were incorporated into the rms error calculation, a smaller rms error would be calculated, and therefore a larger usable sector size would result.

H.2.3 Details of Monopulse Accuracy in Garble Analysis

A formula for the accuracy of monopulse azimuth estimation in the presence of garble was presented in Section 2.1 based on the work of McAulay and McGarty (Reference I-1 and I-2):

$$\varepsilon = (\theta_I - \theta_s) \left[\frac{\rho(\cos \phi + \rho)}{1 + 2\rho \cos \phi + \rho^2} \right] \qquad \text{(I-28)}$$

where

ε = error (BW)
θ_I = azimuth of interferer
θ_s = azimuth of target
ϕ = RF phase difference between target and interferer signals
ρ = interferer amplitude/target amplitude

When dealing with a large number of garbles, it is of interest to know some of the statistics of ε with respect to phase. Those statistics are derived in this Appendix.

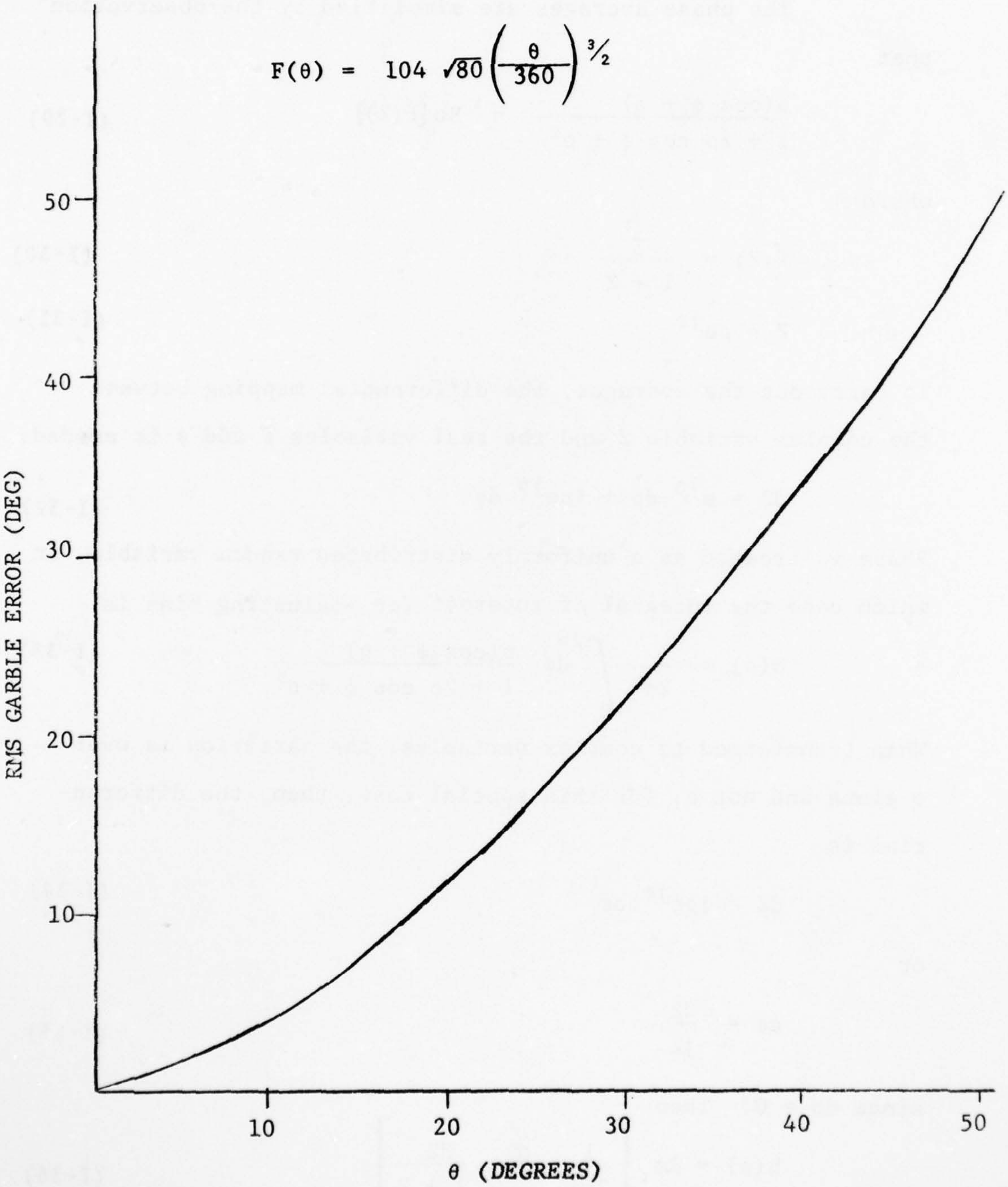


FIGURE I-3

GARBLE ERROR vs SECTOR SIZE (LA-BASIN)

The phase averages are simplified by the observation that

$$\frac{\rho(\cos\phi + \rho)}{1 + 2\rho\cos\phi + \rho^2} = \mathrm{Re}\left[f(Z)\right] \qquad \text{(I-29)}$$

where

$$f(Z) = \frac{Z}{1 + Z} \qquad \text{(I-30)}$$

$$Z = \rho e^{j\phi} \qquad \text{(I-31)}$$

To carry out the averages, the differential mapping between the complex variable Z and the real variables ρ and ϕ is needed:

$$dZ = e^{j\phi}\,d\rho + j\rho e^{j\phi}\,d\phi \qquad \text{(I-32)}$$

Phase is treated as a uniformly distributed random variable, in which case the integral of interest for evaluating bias is

$$b(\rho) = \frac{1}{2\pi}\int_0^{2\pi} d\phi\,\frac{\rho(\cos\phi + \rho)}{1 + 2\rho\cos\phi + \rho^2} \qquad \text{(I-33)}$$

When transformed to complex variables, the variation is over ϕ alone and not ρ; for this special case, then, the differential is

$$dZ = j\rho e^{j\phi}\,d\phi \qquad \text{(I-34)}$$

or

$$d\phi = \frac{dZ}{jZ} \qquad \text{(I-35)}$$

since $d\rho = 0$. Then

$$b(\rho) = \mathrm{Re}\left[\frac{1}{2\pi j}\oint_{|Z|=\rho}\frac{dZ}{1 + Z}\right] \qquad \text{(I-36)}$$

By the residue theorem of complex variable theory, the contour integral equals 0 or 1, depending on whether or not the pole lies inside the contour of integration. Since the pole is at $Z = -1$, the result is

$$b(\rho) = \begin{cases} 0 & : \quad \rho<1 \\ 1 & : \quad \rho>1 \end{cases} \tag{I-37}$$

and consequently the bias is

$$E_\phi(\varepsilon) = \begin{cases} 0 & : \quad \rho<1 \\ \theta_I - \theta_s & : \quad \rho>1 \end{cases} \tag{I-38}$$

The mean squared value is evaluated similarly. What is needed is a function whose real part is ε^2: the function

$$g(Z) = \left[\frac{f(Z) + f^*(Z)}{2}\right]^2 \tag{I-39}$$

is adequate for this purpose because it is equal to the square of the real part of $f(Z)$. Then

$$E_\phi(\varepsilon^2) = \mathrm{Re}\left[\frac{1}{2\pi j} \oint_{|Z|=\rho} dZ \, \frac{g(Z)}{Z}\right] (\theta_I - \theta_s)^2 \tag{I-40}$$

Expanding the square in (I-39) yields

$$g(Z) = \frac{1}{4}\left[f^2(Z) + 2f(Z)f^*(Z) + f^2(Z)^*\right] \tag{I-41}$$

Integrating (I-40) termwise, we see that the f^2 contribution is

$$\frac{1}{2\pi j} \oint_{|Z|=\rho} dZ \, \frac{Z}{4(Z+1)^2} \tag{I-42}$$

which is zero for $\rho<1$ because there are no poles inside the contour. The same is true of the $(f^*)^2$ term. Thus for $\rho<1$, the ff^* term contributes the entire mean squared error. The

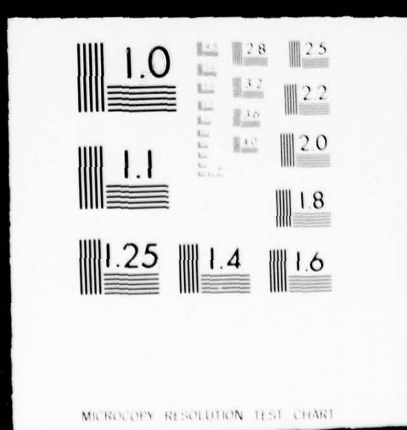
AD-A061 949 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C OFFIC--ETC F/G 17/7
FAA BCAS CONCEPT. VOLUME III B. APPENDICES F - M,(U)
APR 78 E J KOENKE
UNCLASSIFIED FAA-EM-78-5-III-B NL

2 OF 5
AD
A061949

SIFIED

2 OF 5

AD
A061949



integration is easily accomplished using the partial fraction expansion of ff*.

$$f(Z)f^*(Z) = \frac{|Z|^2}{(1+Z)(1+Z^*)}$$

$$= \frac{|Z|^2}{2(1-|Z|^2)} \left[\frac{1-Z}{1+Z} + \frac{1-Z^*}{1+Z^*} \right] \quad \text{(I-43)}$$

Since the integration is over $|Z|=\rho$, the error integral may be written as

$$E_\phi(\varepsilon^2) = \frac{1}{2\pi j} \int_{|Z|=\rho} dZ \; \frac{f(Z)f(Z)^*}{2Z} \; (\theta_I - \theta_s)^2$$

$$= \frac{\rho^2}{4(1-\rho^2)} \; \frac{1}{2\pi j} \int_{|Z|=\rho} \frac{dZ}{Z} \left[\frac{1-Z}{1+Z} + \frac{1-Z^*}{1+Z^*} \right] (\theta_I - \theta_s)^2$$

$$= \frac{\rho^2}{2(1-\rho^2)} \; (\theta_I - \theta_s)^2 \quad : \quad \rho<1 \quad \text{(I-44)}$$

When $\rho>1$, the evaluation of the integrals is somewhat different. All the terms in $(f+f^*)^2$ contribute. The f^2 term is found from the Residue Theorem:

$$\frac{1}{2\pi j} \int_{|Z|=\rho} dZ \; \frac{Z}{4(Z+1)^2} = \frac{\partial}{\partial Z} \left(\frac{Z}{4}\right) \Bigg|_{Z=-1} = \frac{1}{4} \quad \text{(I-45)}$$

This is also the f^{*2} contribution. For ff*, the integral is

$$\frac{1}{2\pi j} \int_{|Z|=\rho} dZ \; \frac{1}{Z(1+Z)} = \frac{1-Z}{1+Z} \Bigg|_{Z=0} + \frac{1-Z}{Z} \Bigg|_{Z=-1} \quad \text{I-46}$$

$$= -1$$

Thus

$$E_\phi(\varepsilon^2) = \left[\frac{1}{2} - \frac{\rho^2}{2(1-\rho^2)} \right] (\theta_I - \theta_s)^2 \quad \text{(I-47)}$$

$$= \frac{2\rho^2-1}{2(\rho^2-1)} \; (\theta_I - \theta_s)^2$$

Since the bias is $\theta_I - \theta_s$, the variance of ε^2 is

$$\sigma_\phi(\varepsilon) = E_\phi(\varepsilon^2) - E_\phi^2(\varepsilon)$$

$$= \frac{1}{2(\rho^2-1)} = \frac{\rho^{-2}}{2(1-\rho^{-2})} \tag{I-48}$$

This last expression shows the symmetry in the azimuth measurement process. When the interference is the larger signal, the target amplitude is ρ^{-1} (<1) relative to the interference, and the variance about the interferer location is the same as in the $\rho<1$ case, with ρ replaced by ρ^{-1}.

I.3. Detection of Phantom Targets

I.3.1 Introduction

One of the problems that faces the BCAS system is the occurrence of so-called "Phantom" targets. For example, it is possible for several airplanes on the ground to produce a spurious signal at the BCAS aircraft that is interpreted as a potential threat at a non-zero altitude. A distinguishing feature of these phantom targets is that they have a velocity that is too small for a flying aircraft. The objective of this section is to determine the feasibility of measuring the velocity of a target and interpreting the target as a phantom if its velocity is below a certain threshold. The basic inaccuracies in such a determination will be analyzed, and the threshold for this decision will be calculated.

It is important to state that the purpose here is to illustrate two possible procedures, one of which is based on statistical decision theory for detecting phantom targets. As shown below, this procedure consists of using relative closing speed data in conjunction with a single shot estimate of the target velocity and azimuth. Since measurement of relative closing speed requires observation over some period of time, it is clear that more than a single shot estimate of target velocity and azimuth is already available for use. Accordingly, it should be emphasized that the following analysis intends only to introduce a specific technique which is amenable to

refinement. An example of a phantom target detection procedure which employs an estimate of the target airspeed based on tracked range, range rate, bearing, and bearing rate is considered second.

I.3.2 Analysis (Decision Theory Applied to Single Velocity Component)

The geometry to be studied is illustrated in Figure I-4. The BCAS aircraft is assumed to have a velocity $\underset{\sim}{V}_o$ and the target aircraft a velocity $\underset{\sim}{V}_T$. The BCAS system measures a range $\underset{\sim}{R}$ to the target, a bearing angle a_z, measured from the direction of flight to the range vector $\underset{\sim}{R}$, in the plane of the BCAS aircraft, and a range rate $\dot{R}$, which is the closing speed between the BCAS aircraft and the target. The range rate is the difference between the projections of the two velocities $\underset{\sim}{V}_o$ and $\underset{\sim}{V}_T$ along the range vector $\underset{\sim}{R}$. The operation of projection utilizes the three dimensional angles α and β as defined in Figure I-4. Using the geometry in Figure I-4, the range rate $\dot{R}$ is

$$\dot{R} = \left|\underset{\sim}{V}_o\right| \cos \beta - \left|\underset{\sim}{V}_T\right| \cos \alpha \tag{I-49}$$

The angle β is derived from the measured parameters

h_o = altitude of the BCAS aircraft
h_T = apparent altitude of the target
a_z = bearing angle to the target

to be

$$\beta = \cos^{-1}\left[\frac{\cos a_z}{\left[1 + \left(\frac{h_o - h_T}{R}\right)^2\right]^{1/2}}\right] \tag{I-50}$$

Inserting this expression into (I-49) for the angle B, the component of the closing speed of the target along the range vector becomes

$$\left|\underset{\sim}{V}_T\right| \cos \alpha = \left|\underset{\sim}{V}_o\right| \frac{\cos a_z}{\left[1 + \left(\frac{h_o - h_T}{R}\right)^2\right]^{\frac{1}{2}}} - \dot{R} \qquad \text{(I-51)}$$

This allows the BCAS aircraft to determine whether or not the target is actually moving towards it. All of the quantities that appear in equation (I-51) are measured by instrumentation on the BCAS aircraft. The range R, the range rate $\dot{R}$, the apparent altitude of the phantom h_T, and the bearing angle a_z are measured by the BCAS system itself. The quantities h_o (the altitude of the BCAS aircraft) and $\underset{\sim}{V}_o$ (the magnitude of the velocity of the BCAS aircraft, which is its ground speed when it is flying parallel to the earth) are assumed to be available from additional instrumentation on the BCAS aircraft.

The threshold value for the decision as to whether or not the target is a phantom is based on the following decision rule: Given that measurements of the necessary parameters are used to provide an estimate $\hat{V}$ of the target closing speed using equation (I-51), the probability of a zero closing speed given the estimate is compared to the probability of a non-zero closing speed given the estimate, and a threshold for the decision is set to minimize the probability of error. If

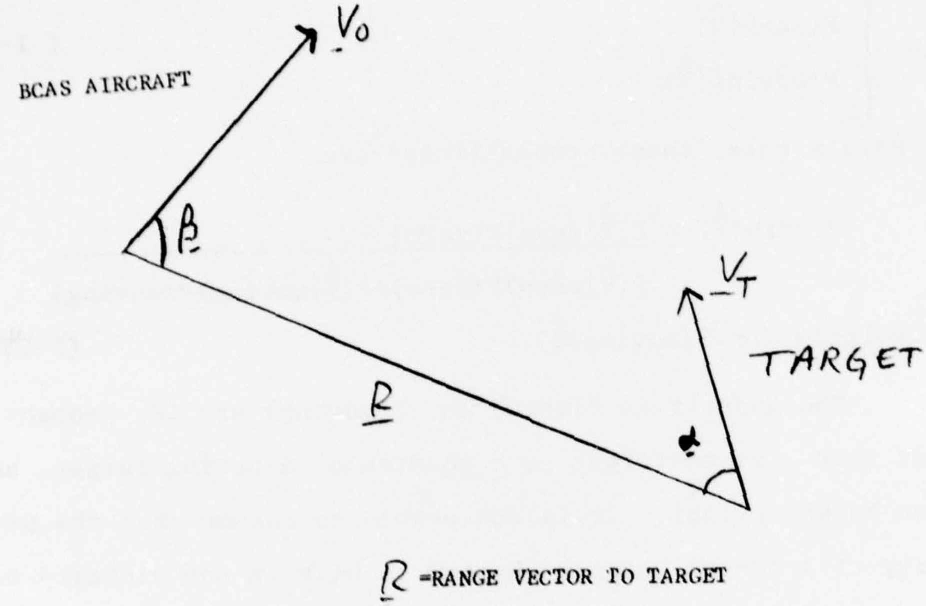


FIGURE I-4 PHANTOM TARGET GEOMETRY

these probabilities are denoted $P(\text{zero}|\hat{V})$ and $P(\text{moving}|\hat{V})$, respectively, the decision rule is

$$\max \begin{cases} P(\text{zero}|\hat{V}) \\ P(\text{moving}|\hat{V}) \end{cases} \qquad \text{(I-52)}$$

Using Baye's rule, these probabilities are

$$P(\text{zero}|\hat{V}) = \frac{P(\hat{V}|\text{zero})P(\text{zero})}{P(\hat{V}|\text{zero})P(\text{zero})+P(\hat{V}|\text{moving})P(\text{moving})}$$

and similarly for $P(\text{moving}|\hat{V})$. **(I-53)**

The quantities P(zero) and P(moving) are the probabilities that a given target is a phantom or a moving target, and are not known apriori. It is reasonable to assume that the probability of a target being a phantom is high in the vicinity of an airport, or that the probability that a target is moving is high away from an airport, but is is not possible to quantify these probabilities any further. For the purposes of this calculation, it is assumed equally likely that a given target is a phantom or moving, so $P(\text{zero}) = P(\text{moving}) = \frac{1}{2}$. Equation (I-51) for the closing speed of the target is used to calculate the two probabilities $P(\hat{V}|\text{zero})$ and $P(\hat{V}|\text{moving})$. This expression gives a relation between the estimate of the target closing speed $\hat{V}$ and the estimates of the other parameters $\hat{R}$, $\hat{\dot{R}}$, $\hat{a}_z$ and $|\hat{\underset{\sim}{V}}_o|$. As a worst case analyses, the BCAS aircraft altitude and the apparent altitude of the target are assumed to be equal. With this assumption, the function that yields the estimate $\hat{V}$ is

$$\hat{V} = |\hat{\underset{\sim}{V}}_o| \cos \hat{a}_z - \hat{\dot{R}} \tag{I-54}$$

This estimate $\hat{V}$ is equal to the actual value of the closing speed plus some error.

$$\hat{V} = V_{ACTUAL} + \varepsilon \tag{I-55}$$

where the error ε is approximately given by the Taylor expansion of (54)

$$\varepsilon = \frac{\partial \hat{V}}{\partial |\underset{\sim}{V}_o|} \varepsilon_{|\underset{\sim}{V}_o|} + \frac{\partial \hat{V}}{\partial \hat{a}_z} \varepsilon_{\underset{\sim}{a}_z} + \frac{\partial \hat{V}}{\partial \hat{\dot{R}}} \varepsilon_{\underset{\sim}{\dot{R}}} \tag{I-56}$$

and $\varepsilon_{|\underset{\sim}{V}_o|}$ and ε_{a_z}, and $\varepsilon_{\dot{R}}$ are random variables that are the measurement inaccuracies on the parameters $|\underset{\sim}{V}_o|$, a_z, and $\dot{R}$. They are taken to be uniformly distributed, and are illustrated in Figure I-5. **Using (I-54) to evaluate the partial derivatives** in (56), the error ε is

$$\varepsilon = \cos \hat{a}_z \varepsilon_{|\underset{\sim}{V}_o|} - |\hat{\underset{\sim}{V}}_o| \sin \hat{a}_z \varepsilon_{a_z} - \varepsilon_{\dot{R}} \tag{I-57}$$

The probability density function for the error ε is obtained by convolving the densities for $\varepsilon_{|\underset{\sim}{V}_o|}$, ε_{a_z}, and $\varepsilon_{\dot{R}}$. Three sample calculations will be presented to illustrate the Baye's Rule detection procedure. In all cases, the following parameters values will be used (see Figure I-5).

V_o = the maximum error in the BCAS aircraft speed error = 10 knots

a_z = the maximum error in bearing angle = 6 degrees

$\dot{R}$ = the maximum error in the range rate = 10 knots

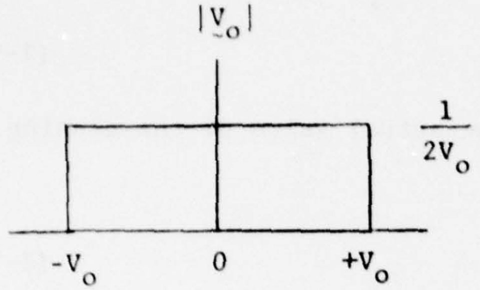


Figure a $\varepsilon_{|\underset{\sim}{V}_o|}$

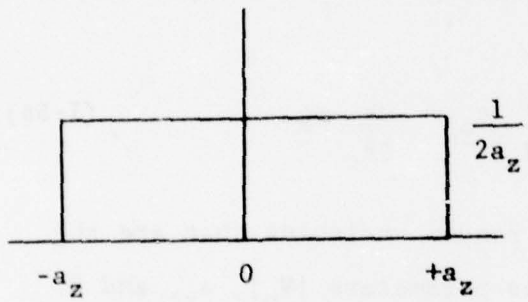


Figure b ε_{a_z}

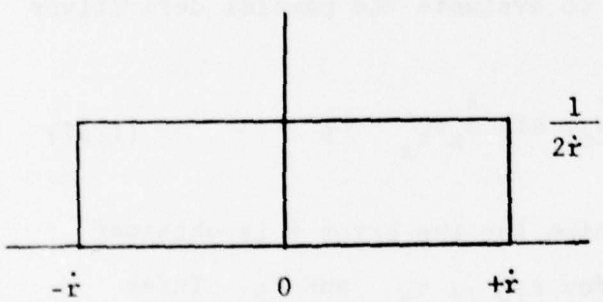


Figure c $\varepsilon_{\dot{R}}$

Figure I-5

Probability density Functions for the random variables $\varepsilon_{|\underset{\sim}{V}_o|}$, ε_{a_z}, and $\varepsilon_{\dot{R}}$

Also, we arbitrarily assume that if a target has a closing velocity of 50 knots or more, it is deemed a moving or real target, and if it has a closing velocity less than 50 knots, it is a phantom target. Given the preceding data, the threshold value for such a decision using Baye's rule in (I-52) will be calculated.

<u>Case 1</u> Bearing Angle $a_z = 0$

In this case, the error ε is

$$\varepsilon = \varepsilon_{|\underset{\sim}{V}_o|} - \varepsilon_{\dot{\underset{\sim}{R}}} \qquad \text{(I-58)}$$

The interpretation of this result is that when the target appears to be directly in front of the BCAS aircraft, small errors on the bearing angle are unimportant. The probability density function for ε in this case is illustrated in Figure I-6. Using this density function to compute the densities $P(\hat{V}|\text{zero})$ and $P(\hat{V}|\text{moving})$, the aposteriori probabilities $P(\text{zero}|\hat{V})$ and $P(\text{moving}|\hat{V})$ for this case can be calculated, and are illustrated in Figure I-6. In this case a decision is easily reached, as all of the estimates indicate either a moving target or a phantom. The threshold is arbitrary in the region 20 knots $< \hat{V} <$ 30 knots.

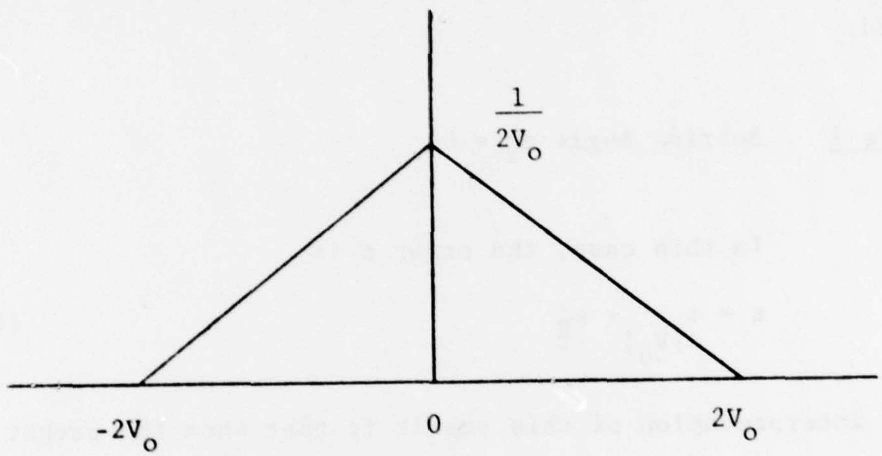


Figure I-6: Probability density function for the error ε when the bearing angle is zero.

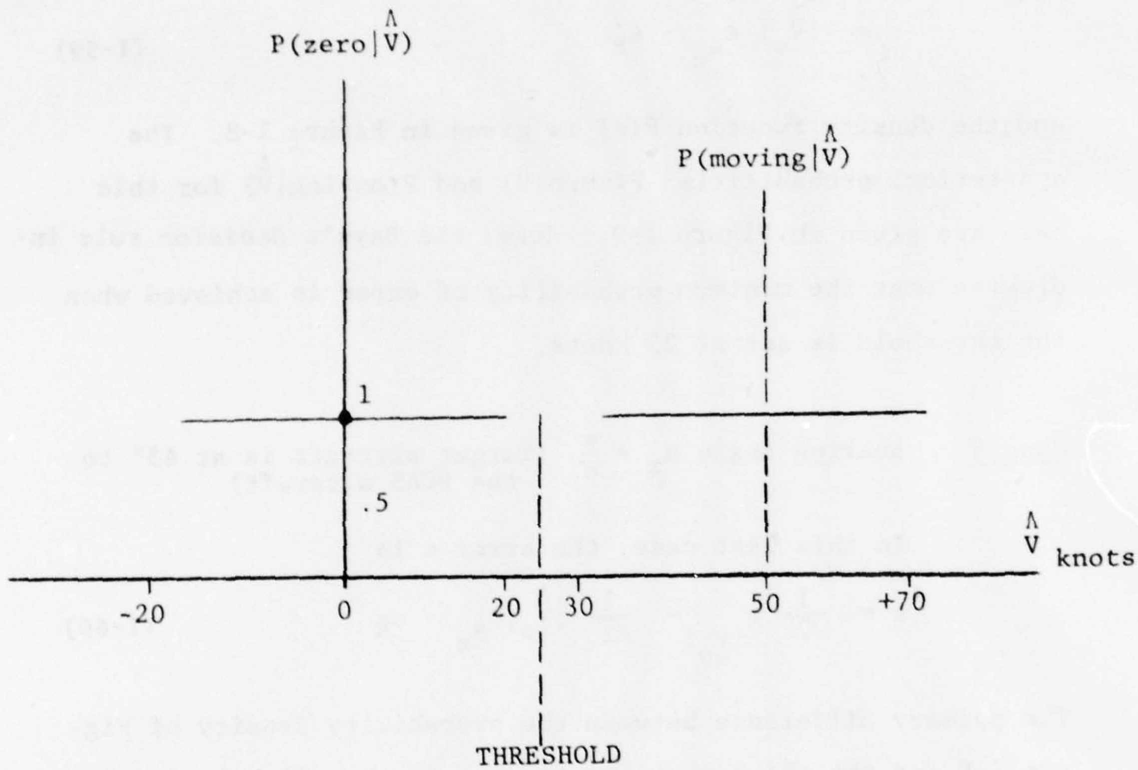


Figure I-7: The aposteriori probabilities for the Baye's decision in (I-52), for bearing angle = 0.

Case 2 Bearing angle $a_z = \frac{\pi}{2}$ (Target aircraft is broadside to the BCAS aircraft)

In this case, the error ε is

$$\varepsilon = -|\hat{\underset{\sim}{V}}_o| \, \varepsilon_{a_z} - \varepsilon_{\dot{R}} \tag{I-59}$$

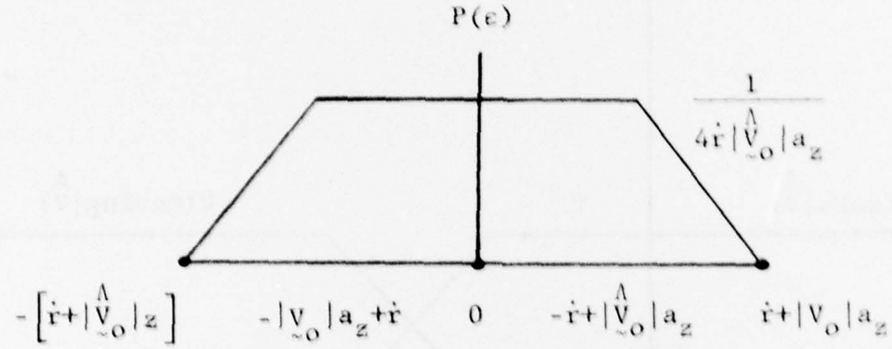
and the density function $P(\varepsilon)$ is given in Figure I-8. The aposteriori probabilities $P(\text{zero}|\hat{V})$ and $P(\text{moving}|\hat{V})$ for this case are given in Figure I-9. Here, the Baye's decision rule indicates that the minimum probability of error is achieved when the threshold is set at 25 knots.

Case 3 Bearing angle $a_z = \frac{\pi}{4}$ (Target aircraft is at 45° to the BCAS aircraft)

In this last case, the error ε is

$$\varepsilon = \frac{1}{\sqrt{2}} \varepsilon_{|\underset{\sim}{V}_o|} - \frac{1}{\sqrt{2}} |\hat{\underset{\sim}{V}}_o| \varepsilon_{a_z} - \varepsilon_{\dot{R}} \tag{I-60}$$

The primary difference between the probability density of Figure I-8 and the one pertaining to (60) is the slightly increased smoothness of the latter. This further implies that the corresponding aposteriori probabilities have slightly different shapes. Analysis, however, once again shows the threshold value of velocity to be 25 knots.



<u>Figure I-8</u>: The density function $P(\varepsilon)$ for the case when the bearing angle $a_z = \frac{\pi}{2}$

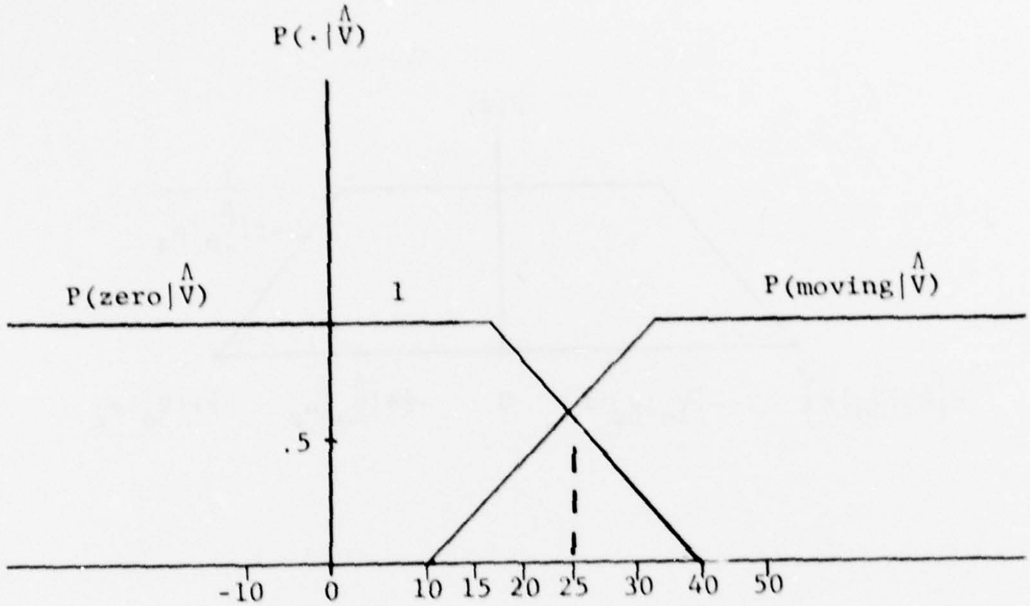


Figure I-9: The aposteriori probabilities for the maximum likelihood decision in (52) for a bearing angle $= \frac{\pi}{2}$.

I.3.3 Estimation of Target Airspeed

As in the previous section, the analysis will be done in two dimensions, assuming the worst case situation, BCAS and target at equal altitude.

Referring back to Figure I-4, we see that target velocity components other than the one along the range vector can be solved for given the data in the active tracker (r, $\mathring{r}$, β, and $\mathring{\beta}$). The BCAS velocity vector $\underline{V}_B$ and the range vector $\underline{R}$ are related to the bearing β as follows

$$\underline{V}_B \cdot \underline{R} = |\underline{V}_B| r \cos \beta \tag{I-61}$$

where

$$r = |\underline{R}| \tag{I-62}$$

Assuming $\underline{V}_B$ to be a constant, we can differentiate both sides of (61) to get

$$\underline{V}_B \cdot \mathring{\underline{R}} = |\underline{V}_B| (\mathring{r} \cos \beta - r\mathring{\beta} \sin \beta) \tag{I-63}$$

$\mathring{\underline{R}}$ is of course the difference in the target and BCAS velocities,

$$\mathring{\underline{R}} = \underline{V}_T - \underline{V}_B \tag{I-64}$$

By substituting the above in (I-63) we can solve for V_{TB}, the target velocity component along the BCAS velocity vector:

$$\begin{aligned} V_{TB} &= \underline{V}_T \cdot \left(\frac{\underline{V}_B}{|\underline{V}_B|}\right) \\ &= V_B + \mathring{r} \cos \beta - r\mathring{\beta} \sin \beta \end{aligned} \tag{I-65}$$

where

$$V_B \triangleq |\underline{V}_B| \tag{I-66}$$

This result complements the one derived in Section I. 3.2 for the component along the range vector. In terms of our notation, that component is identified as V_{TR}:

$$V_{TR} = \dot{r} + V_B \cos \beta \tag{I-67}$$

Knowing V_{TR} and V_{TB}, the speed of the target can be estimated. Since we are working in an oblique coordinate system (the components measured are along vectors separated by angle β), the target velocity vector is found by taking a linear combination of the basis set which is biorthogonal to $\underline{V}_B$ and $\underline{R}$. Those vectors have magnitude csc β and separation $\pi - \beta$. It follows that

$$\begin{aligned} |\underline{V}_T|^2 &= \frac{1}{\sin^2\beta} \left[V_{TB}^2 - 2V_{TB}V_{TR} \cos \beta + V_{TR}^2 \right] \\ &= V_B^2 + 2V_B\dot{r} \cos \beta + \dot{r}^2 + r\dot{\beta}(r\dot{\beta} - 2V_B \sin \beta) \end{aligned} \tag{I-68}$$

A threshold test can be made directly on (68) to detect presence of phantoms; sufficiently low airspeed (e.g., < 50 knots) implies that the target is a phantom.

I.3.4 Conclusions:

As a result of the calculations in Section I.3.2, it is tempting to conclude that the major factor that affects the value of the threshold for the decision as to whether a target is a phantom or not is the apriori probability that the target is a phantom.

Once a threshold value has been calculated, it seems to be relatively independent of the other parameters in this problem, such as the tolerances on measurement of the BCAS aircraft velocity or the bearing angle a_z. So, in an environment where the probability that a target is a phantom is high the threshold for deciding the identity of a target is also high, and conversely in an environment where the probability that a target is actually moving is high.

The result of this decision is that the target is or is not moving towards the BCAS aircraft. A further decision must also be made, in that it is possible that the target is moving parallel to the BCAS aircraft. Formulas for that determination are given in Section 3.3. One has then a choice of developing algorithms which use the two velocity components independently or making a simpler test based on estimated airspeed.

APPENDIX I - REFERENCES

1. R.J. McAulay, "The Effects of Interference on Monopulse Azimuth Estimation Accuracy", ATC Working Paper 42 WP-5002, M.I.T. Lincoln Laboratory, Lexington, Massachusetts, (7 March 1973).

2. R.J. McAulay and T.P. McGarty, "Optimum Interference Detection", Laboratory Technical Memorandum 42L-048, M.I.T. Lincoln Laboratory, Lexington, Massachusetts, (18 January 1973).

APPENDIX J

REPLY PROCESSOR SUPPLEMENTARY DETAIL

APPENDIX J

Reply Processor Supplementary Detail

Section 4.2.4 outlines the overall structure of the BCAS reply processor in general and does not develop much detail. In this appendix we present the details of reply processor/trackers for two BCAS modes:

(i) Active Mode

(ii) Semi-Active ATCRBS/RBX Mode

J.1 Active Mode-ATCRBS Target

An active mode BCAS which can form range/altitude tracks has been designed and tested. The reply processor/trackers for this system has been documented by Reference J-2, and much of the following is an extension of Clark's work

which accomodates the capability of target bearing measurement via the steerable circular phased array.

Active mode targets are acquired by processing target reports out of the returns from a succession of active interrogations. Ideally, an active mode target report consists of range, altitude, and bearing. In the tracking logic set forth here, bearing estimates are given various confidence levels which affect their impact on track initiation, extension, and termination. Within this scheme, target reports which have no bearing estimate are permitted, and target tracks based on such estimates may be "coasted" in bearing for short time periods. The rules of extension and termination will define the relevant circumstances explicitly.

J.1.1 Track Initiation

Track initiation requires a succession of target reports. Thus we must first define a target report and how its constituents are determined.

J.1.1.1 Target Reports

In response to an active interrogation, the BCAS receiver seeks to identify target replies by detection of bracket pairs, i.e., F_1 F_2 pulse pairs separated in arrival

time by 20.3 μs. When a pulse arrival is detected in the sum beam, the difference beam is formed and an angle of arrival estimate is made on the pulse. The arrival time is measured and stored and used to ensure that the pulse slot occurring 20.3 μs later is examined for a possible pulse. If a pulse is found in the F_2 slot, its angle of arrival is also measured and the appropriate intervening locations are examined for pulse content so that an altitude or ID code can be read. Angle estimates are not made on the code slot pulses.

In addition, an interference detection statistic is formed from the complex sum and difference beam outputs (Σ and Δ) on each of the bracket pairs as follows:

$$I = \Big| \, |\Sigma + j\Delta| - |\Sigma - j\Delta| \, \Big| / |\Sigma|$$

This statistic has been discussed in Reference J-1, and is essentially a measure of the relative phase distortion that occurs between Σ and Δ when interference is present. The interference statistic is compared to a threshold, and if the threshold is exceeded, a garble flag is set for that bearing estimate.*

*/ The interference statistic is used conservatively in the reply processor because it can be shown that whereas a large value of I definitely indicates presence of interference, a small value does not as definitively indicate absence. Certain phase relationships can occur which cause failure to detect even large garbles.

For each pulse pair found at the F_1 F_2 spacing, the ingredients listed above are formed into a target report as follows. A range (r) is computed based on the pulse pair arrival time relative to the time of interrogation. For the bearing* computation, there are available both an F_1 and and F_2 bearing estimate and a garble flag for each. By the procedure shown in Figure J-1, a single bearing and a 4-level confidence factor are extracted from the data. The procedure basically involves comparing the F_1 and F_2 bearings, checking that they are within coverage, and deciding in favor of the "cleaner" bearing in cases of disagreement.

The bearing computation has three possible outcomes. The normal outcome is the calculation of a Level 1 or Level 2 bearing. In some cases (e.g., both garble flags are set, the bearings are unequal but both within coverage), the bracket pair is retained but it is impossible to assign a meaningful bearing and a null code is entered into the bearing field of the target report. The third possibility (e.g., neither flag is set, the bearings agree but are out of coverage) is that the entire point is rejected on the basis of bearing and no target report is generated.

---

*/ In this section, "bearing" is defined relative to the BCAS aircraft heading, not magnetic North.

The four levels of bearing confidence are as follows:

Level 1: Both F_1 and F_2 are ungarbled

Level 2: One of F_1 and F_2 is garbled

Level 3: Both are garbled, but bearings agree

Level 4: Bearing is rejected

The altitude or ID code is appended to the target report. For altitude, the Gray code is retained for future altitude data processing (if desired, binary altitude may also be stored). For each target report, altitude is retained even if it corresponds to an illegal code on the chance that the target report will correlate with other reports carrying legal codes during track initiation.

J.1.1.2 Correlation of Target Reports

J.1.1.2.1 Range Correlation

Track initiation can begin after target reports from four consecutive interrogations in the same antenna beam have been obtained. Track points will be identified by an age index, e.g., r_1 is the most recent range and r_4 is four samples old.

Since range is probably the most reliable of the active BCAS measurements, the first selection for points to be associated in a track file is based on range. The first step is to find all range pairs $r_2^{(j)}$, $r_3^{(k)}$ ($r_2^{(i)}$ is the i-th point in the r_2 list, etc.) whose difference could correspond to a real target of interest. The difference

$$\dot{r} = r_2^{(j)} - r_3^{(k)}$$

is a rough estimate of range rate. Closing targets are naturally of great concern for BCAS, and these have negative range rates. However, cross-range or slightly outbound targets (especially close ones) are of interest too, so the range of acceptable $\dot{r}$ is from a large negative value (e.g., -1200 knots) up to a small positive one (e.g., 50 knots).*

Every pair of points satisfying

$$-\dot{R}_- \leq r_2^{(j)} - r_3^{(k)} \leq \dot{R}_+$$

is retained as an initial track candidate. The next step is to develop trial 4-point tracks by associating two endpoints from the target report file, $r_1^{(i)}$ and $r_4^{(\ell)}$, with each $r_2^{(j)}$, $r_3^{(k)}$ pair passing the $\dot{r}$ test. A straight line is fit through the two middle points (r_2, r_3) and all points (r_1, r_4) lying within some $\pm\ \Delta r$ of the linear fit are determined. If there are none, no track is formed. Or, if there are r_1's but no r_4's (or vice versa), no track is formed. Each (r_1, r_4) pair that

---

*/ The lower $\dot{r}$ limit can be varied in accordance with the maximum BCAS airspeed.

qualifies is used to initiate a track. Thus if there are 2 r_1's and 6 r_4's, 12 tracks are started using the given (r_2, r_3) pair.

Once a tentative range track is found, an improved estimate of $\overset{o}{r}$ can be obtained;

$$\overset{o}{r} = \frac{r_1^{(i)} - r_4^{(\ell)}}{3}$$

is one such estimate. Its standard deviation is one-third that of the initial one. A second one is the slope of the best linear least squares fit, which can be shown to have comparable accuracy.

Although it may seem excessive to start tracks on all (r_1, r_4) pairs through each eligible (r_2, r_3) pair, it is more important to find all true tracks initially at the expense of retaining a number of short false tracks. In addition, if garble flags have been set on either or both of the r_2, r_3 points, then it is quite likely that there are multiple tracks passing through those points, making it especially important to test all possible initial tracks. This point is kept in mind in determining the integration of bearing data into track initiation.

J.1.1.2.2 Bearing Correlation

There are several paths that can be followed in using

bearing data to select initial tracks, depending on the nature of the available data. Recall that there can be some target reports retained without a bearing entry. And those bearings which are available can have varying confidence level assignments. Below we trace the procedure for all the possible cases. The major subdivision between cases is based on the number of bearing points in the target reports making up four range points which have passed all the range tests.

Case 0: No Bearing Points

When no bearing is available, tracks are initiated on range and altitude alone.

Case 1: One Bearing Point

An isolated bearing point is useless for track correlation, so in this case track initiation is also based on range and altitude alone.

Case 2: Two Bearing Points

Compute a bearing rate $\mathring{\beta}$ according to

$$\mathring{\beta} = \frac{\beta_i - \beta_j}{j - i}$$

and test it for track realism by comparing $|\mathring{\beta}|$ to a threshold. If $|\mathring{\beta}|$ exceeds the threshold, the initial track may be dropped. If it passes the test, retain the track. Note that the threshold should be a decreasing function of $|i-j|$, since the slope is more accurate when the points are more distantly separated Also, if either or both bearings are Level 3, the bearing test should not be applied and initiation based on range and altitude will suffice.

Case 3: Three Bearing Points

With three points, make a least squares fit and perform a $|\mathring{\beta}|$ test on the slope; retain the track if the track passes the test. At option, the total squared deviation from linear can be tested and required to be sufficiently small. If the 3-point $\mathring{\beta}$ test fails, test all three 2-point fits to see if exactly one of these passes the test. If so, retain the track; otherwise it is dropped. The vacant spot in the track file that is set up can be filled with the least squares point. But the least squares point should not be added to the target report, because that point may be involved ir initiating other tracks as well.

Case 4: Four Bearing Points

Begin as in the previous case, i.e., find the least squares fit and perform the slope test. If it passes, retain

the track. If not, delete the lowest confidence level point (ties are resolved by deleting the point of lowest confidence which is also furtherest from the least squares fit) and try the 3-point fit and $\dot{\beta}$ test. If this too fails, the track is dropped; success means retention of the track. If track acceptance is based on the 3-point test, the deleted bearing value is replaced by the least squares fit point in the new track file, but not in the target report.

J.1.1.2.3 Altitude Correlation

The main issue in altitude correlation is degarbling the replies, not accurate estimation of altitude and altitude rate. Thus the four altitude codes are reduced to a single code by logically "anding" the codes bit-for-bit. This will leave a zero in the resultant code in any pulse position which shows a detected zero in the corresponding position of any of the four target report codes. This technique exploits the observation made many places in the main text (e.g., Section 4.2.4) that in a garble environment, a detected "zero" (no pulse) is very likely to be the correct code digit, whereas a detected "one" can either be the correct pulse or a fill-in resulting from garble. The new track is accepted or dropped, depending on whether the anded altitude is a legal code and lies within a certain band (say $\pm$ 5000 ft) around the BCAS altitude. It is recognized that this anding technique could

produce erroneous results if applied over periods of time longer than the 4s involved in initiating an active mode track.

Altitude rate is initialized at $\dot{Z} = 0$.

Naturally, Mode A-only targets will provide no altitude returns, and such targets can be initiated and tracked in range and bearing only.

J.1.1.2.4 ID Correlation

ID is the least reliable tracking parameter because codes are often changed by the ground controller, and for ATCRBS the ID's are far from unique (many low-altitude targets will use code 1200). The ID codes of all mode A reples are anded together to generate the track ID. No accept/reject tests are applied to the resultant code.

J.1.2 The Track File

When a set of four points has satisified all the track initiation test previously described, a track file is set up for the target. Targets will be tracked in range, bearing, and altitude using second-order linear predictive tracking, such as (α, β) tracking. The track file must be initialized for the (α, β) tracker using the data obtained during initiation.

One single method of initialization is illustrated here for range, but applies to the other two coordinates as

well. The range r_4 and the recomputed range rate $\mathring{r}$ can be input to the (α,β) as initial conditions and the tracker can start to run, taking r_3, r_2 and then r_1 as new inputs. The predicted (smoothed) points output by the tracker can replace the initial track points, and extensions to the file can be made as new data comes in. This will be discussed in detail in the next section.

For bearing, the filter initiation may have to be modified since some target reports may not have bearing. The simplest idea is that when future target reports have bearing data, a bearing track can be initiated. If no consistent bearing is found, the track will eventually be dropped.

Each (α, β) tracker continually estimates one coordinate and its derivative, and thus current estimates of r, $\mathring{r}$, β, $\mathring{\beta}$, z, and $\mathring{z}$ will be available. In addition, the active mode tracker must keep ID (if available) and a beam index indicating which antenna beam the track is found in. Use of the beam index will considerably simplify the search procedure required in track extension; by looking at a single number (beam index) it is possible to determine whether a new data point should be tested against a given file, without going into more elaborate coordinate matching tests. Note that the beam indexing must be adaptive to aircraft heading, because a BCAS turn maneuver will move the beam relative to the targets. Because of this and target motion, some targets will occasionally transition

from one beam to another. An algorithm to detect impending beam transitions should be easy to formulate and its output should be an (old, new) pair of beam indices indicating which two beams the target is likely to occupy. The track file must provide space to store both indices.

J.1.3 Track Extension

In this section we will only deal with those normal extensions which occur when a track is fully initiated, i.e., all data (including bearing) is present. Special cases relating to starting up with missing bearing information are under study as work is in progress.

Track extension basically occurs as follows: the (α, β) tracker for any coordinate contains, as part of its state vector, a current estimate of the coordinate derivative and a prediction of the next value to be taken on by the coordinate. The use of these is illustrated for range.

Given the data up to time 1, a prediction $\hat{r}_o$ of the range at time 0 is made by the smoothing filter. This is compared to the measured target range r_o (forget, for the moment, that in a multi-target tracker there can be ambiguity as to which measured range should be associated with the given track), and the prediction error

$$\varepsilon = \hat{r}_o - r_o$$

is fed back into the filter in order to predict the next point. In the process of generating $\hat{r}_o$, a rate estimate for time 1, $\hat{\dot{r}}_1$ is also generated. The predicted points and the internally-estimated rates $(\hat{r}_i, \hat{\dot{r}}_i)$ constitute the track for that coordinate.

Obviously, the crux of the track extension problem for active mode BCAS is the correlation of replies with the correct track. We shall continue to assume, as we did in track initiation, that range is the most reliable coordinate in garble, because it is measured by arrival time of a reply bracket pulse pair; garble is unlikely to destroy either framing pulse, but is rather more likely to simply jitter the arrival times in a way that can be smoothed in the tracker. Monopulse-determined bearing can fluctuate over a significant fraction of a beamwidth due to differential phase effects in the superposition of pulses; altitude codes can be garbled but at least have the virtue that real altitude does not change frequently or rapidly, so that many samples can be jointly processed in the attempt to read true code.

In simple terms, three elementary principles govern track extension:

(i) If you find a new target report that matches your track, use it;

(ii) If no matching target report is found, coast the track;

(iii) If a track has been coasted for too long, drop it.

The subsections which follow show how each of these principles (and their exceptions) can be incorporated into the active mode track extension logic.

J.1.3.1 Testing for Matching Extension

The range test for matching extension is relatively easy. A track is selected from the track file and its beam index is (or indices are) noted; initially assume there is but a single index. Entries in the Time 0 target report file whose beam index matches the track beam index are tested to find those reports whose ranges are within Δr of the predicted range for the track in question. Put another way, those points which give rise to a range prediction error $|\varepsilon|<\Delta r$ are retained.

Simultaneously, a similar search is conducted over bearing. The bearing search is only slightly complicated by the fact that the admissible prediction error is tested against two limits, $\Delta\beta_1$ and $\Delta\beta_2$ ($\Delta\beta_2>\Delta\beta_1$). Points outside the larger

limit are not retained, those within the smaller limit are retained. Those in between are viewed as probably consistent with the given track, but which have a larger than normal garble bias. The (assumed) garble bias can be dealt with in a number of ways. As an illustrative example, any target bearing giving rise to a $\Delta\beta$ satisfying

$$\Delta\beta_1 < |\Delta\beta| < \Delta\beta_2$$

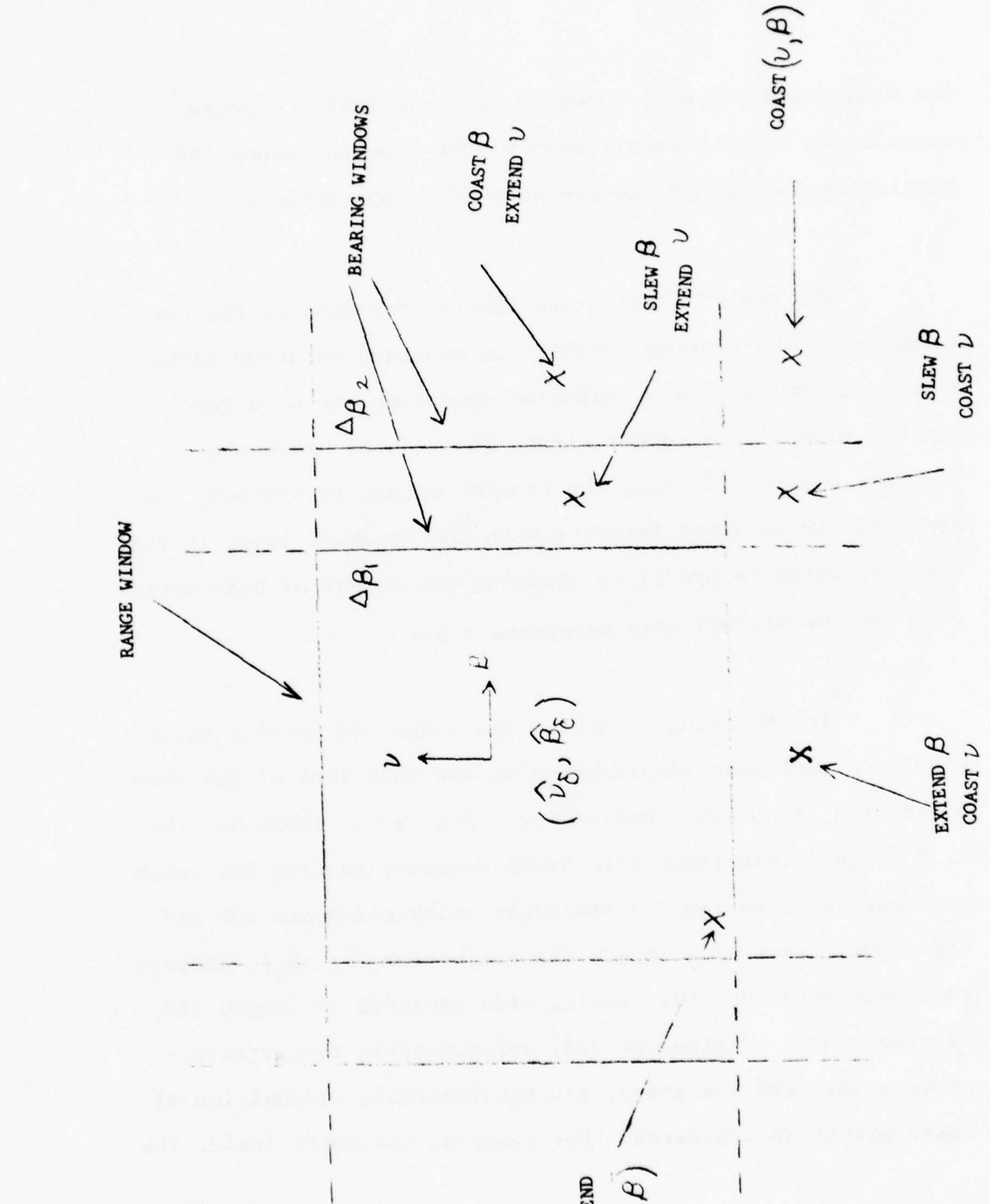
can be truncated so that the $\Delta\beta$ corresponding to the truncated bearing equals $\Delta\beta_1$ in magnitude; of course the truncation is done in the way that retains the original algebraic sign of $\Delta\beta$.

A device which performs such an operation is known as a slew rate limiter. The rationale for slew rate limiting is to eliminate anomalous data which indicates target kinematics incompatible with the physical targets being tracked. Realize, of course, that the measurements under discussion are in a BCAS-referenced coordinate frame and this must be taken into account, for example, by feeding the current BCAS airspeed into the reply processor/tracker as an input to determination of the slew rate thresholds. A slew rate limiter then takes data which is intermediate in quality between perfectly acceptable and unacceptable and gives it the benefit of the doubt by slewing it into the acceptable class. Obviously, slew rate limiting is a sensible data processing technique only when

the measurements can be expected to occasionally produce anomalously large errors. Such is the case for monopulse bearing estimation in the presence of active garble.

The use of a slew rate limiter can enhance the performance of the bearing tracking in moderate to heavy garble. Slew rate limiting is a nonlinear operation and as a result, the net effect is a rather strong function of where the limiting occurs. If only the tracker output is limited, the nonlinearity does not interact with the feedback loops in the tracker, which is useful in limiting the amount of bias introduced by the tracker (See Reference J-3.)

In the actual tracker, the range and bearing tests should be performed simultaneously, and thus some of the above discussion is possibly misleading. Figure J-2 shows how the r, β space is partitioned in simultaneously testing for range and bearing extension. A rectangle whose sides are $2\Delta r$ and $2\Delta\beta$ symmetrically surrounds the projection $(\hat{r}_o, \hat{\beta}_o)$. Another rectangle which has its bearing side extended to length $2\Delta\beta_2$ is also shown. Various points, corresponding to target reports under test are shown, and the tracker's disposition of these points is indicated. For example, the point inside the


RANGE WINDOW
BEARING WINDOWS
$\Delta\beta_1$
$\Delta\beta_2$
COAST β
EXTEND ν
SLEW β
EXTEND ν
COAST (ν, β)
SLEW β
COAST ν
EXTEND β
COAST ν
(ν, β)
$(\hat{\nu}_\varepsilon, \hat{\beta}_\varepsilon)$
ν
β
EXTEND
(ν, β)

smaller rectangle is extended without modification because both the range and bearing lie within the unconditional acceptance window. The five other points in distinct partitions show all the remaining options. The six total options are all combinations of

$$\text{Range:}\left\{\begin{array}{l}\text{Extend}\\ \text{Coast}\end{array}\right.\qquad\qquad \text{Bearing:}\left\{\begin{array}{l}\text{Extend}\\ \text{Slew}\\ \text{Coast}\end{array}\right.$$

As indicated earlier, more than one point lying in any of the r, β regions potentially indicates a multiple extension. Final outcome of course depends on the remaining tests, but when multiple extension occurs, the track file is copied into a new file location N-1 times (for N extensions) and each extension is treated as a new track. Since tracks tend to proliferate from both the initiation and extension processes, means to eliminate false tracks and duplicate tracks must be made available. This will be discussed subsequently.

Returning to the extension algorithm, we mention one additional procedure which is invoked before range and/or bearing is to be coasted. If the track has a second beam index stored, the current bearing is near the beam edge, and the bearing rate is consistent with motion into the adjacent beam sector, then target reports from that beam should be examined for possible extension before a decision to coast is made.

If neither range nor bearing extension is possible within the track beam, then a point in the adjacent beam which matches in either range or bearing will be accepted, and the unmatched coordinate is coasted. If range is already matched, then only a point matching in both range and bearing will be taken. However, an initial bearing match can be discarded in favor of a new target report that has range match and bearing that is close enough ($\Delta\beta_2 < \Delta\beta < \Delta\beta_3$). The bearing will still be coasted.

J.1.3.2 Coasting

When it is determined that a track coordinate should be coasted, the procedure is easy. The predicted coordinate is used to replace the missing measured coordinate in the α,β filter. In other words, zero prediction error is fed back into the filter, which will cause it to project linearly for the next prediction at the most current rate estimate. The coordinate rate estimate is unchanged by this. Thus the data processing for coasting is quite simple.

J.1.3.3 Altitude Extension

Altitude extension in the absence of garble should try to capitalize on two features: (i) altitude changes slowly (less than 100 ft. between BCAS measurements) and in some cases infrequently, and (ii) adjacent altitudes have codes differing in only

one bit (Gray code property). The active tracker (reference J-1) exploits these features by rounding the altitude prediction z_o to the nearest 100 ft., and then looking for the codes corresponding that flight level $\pm$ 100 ft. A third principle also used in [J.17] is that newly discovered zeroes in an altitude code should be given fairly strong weighting, because it is likely that those occur due to the disappearance of a garble pulse. Coupling altitude level checks with garble correction should produce reliable altitude tracks.

When an altitude code changes, some changes are more preferable from the tracker point of view than others, in terms of what they mean about the code garble condition. The most favorable changes (ranked in decreasing preference) are:

(i) An uncovered zero which changes z by 100 ft;
(ii) An added one which changes z by 100 ft;
(iii) An uncovered zero which changes z by only a few hundred feet;
(iv) An uncovered zero and an added one which change z by only a few hundred feet;
(v) Two uncovered zeros that change z by only a few hundred feet;

etc. The cases of concern are when the uncovering of a single zero produces a large change in altitude. This may imply that the altitude code which is being tracked is garbled and highly erroneous.

The tracker deals with the problem of garble by correlating the target report altitude code with the predicted code and the $\pm$ 100 ft. incremental altitude codes. The correlation process is rather complex and involves counting the number of garbled ones and dropped ones in the code to estimate the correlation statistics (see Clark [3.1]). When there is good correlation with a local code, i.e. within $\pm$ 100 ft. of prediction, that has no new zeros, a normal extension is made. If a new zero occurs that generates a non-local code, an altitude corrected extension is made which involves resetting both z and $\dot{z}$ **(reference J-1)**

The decision to extend (normal or corrected) or coast is made on a sample-by-sample basis in the tracker. More accurate garble resolution should be possible if a number of successive altitude codes are retained and examined for changes in the garble environment. Development of procedures to do this is work in progress.

J.1.3.4 ID Extension

ID can be used as a track label, although since ID can be garbled it is not a perfectly reliable indicator. After the range/bearing extension has been accomplished, ID should be checked. If it matches, there is no concern. If not, successive ID's on the extension of the given track should be examined.

The logical "and" of these should provide correct ID. Anding can be applied in a sliding window manner if desired.

If a permanent-looking change in ID seems to have occurred, the remaining tracks in the current beam sector should be searched for matching ID to see if a multiple track exists or if a track "switch" has occurred on the original track at the point of altitude change. This is discussed further under Track Merge and Track Elimination.

1.4 Track Merge

After new target reports have been received, new track files set up, and all tracks extended, a track merge procedure must be entered to eliminate duplicate tracks. This will be considerably easier than in an omnidirectional active tracker, because only track pairs having identical beam indices need be compared. The purpose of the comparison is to detect tracks which are nearly identical and eliminate all but one of those. A procedure for this is described below.

The most likely place for duplication to occur is in forming a new track for a target already in track. To detect these duplicates, track pairs consisting of one new track and one extended track taken from one beam are compared. The comparison consists of comparing range, range rate, bearing,

bearing rate, and altitude (altitude rate is not used because $\dot{z}$ is set equal to zero in a new track). The criteria used in determining whether the tracks are duplicate should be rather lax in this case, because data in the new track file has not had the benefit of much smoothing time. The criteria can be tightened later when two established tracks are compared.

Two comparison techniques are outlined below. In the first, five coordinates are compared directly by thresholding on the magnitude of their difference. These can be done sequentially, testing on the more reliable indicator first. For example, the range test can be made and if the difference is too large, the comparison can be terminated immediately. Bearing, range rate, and bearing rate are sequentially tested in the same way. If the track matches in all these, altitude is tested and the outcome is treated as follows: if match, the track is a duplicate and the new track is dropped. If there is an altitude mismatch, the new track may be a duplicate but is not dropped, because the mismatch may be due to a garbled bit. As the track is entered into the old track file, it is flagged with the name of its companion track, for a more detailed comparison on subsequent merges. Details of such a procedure constitute work in progress.

A second idea is to generate estimates of the target position and velocity vectors (these can be relative to BCAS

for the present purpose). These estimates can be generated from r, $\overset{\circ}{r}$, β, and $\overset{\circ}{\beta}$. The comparison is then made first on position, then velocity. Altitude can be checked first and included in the position calculation if there is a match, and excluded if there is not. A comparative study of these two and similar techniques is required to finalize this phase of the merge.

All new tracks which survive the first phase of the merge are entered into the old (or existing) track file. However, this is not done until the second phase, described below, is completed.

The second phase of the merge is to compare existing track pairs. Tracks of low age index are excluded from this comparison. In this test, the standards can be more strict because the tracks have been smoothed and are more accurate. Identical tracks may not have been purged in the first phase, because the new track points, although identical prior to smoothing, are not necessarily identical at the (α, β) output due to the difference in track history in the old and new tracks. The comparison procedure can be almost the same as in Phase I, except that track age can be included in the comparison. When duplicates of different age are discovered, the older track is retained (this logic may be expanded to include tests related to number of coasts and altitude corrections).

Treatment of tracks identical except in altitude is as in the first phase.

J.1.5 Track Elimination

Track elimination is the process of deleting false tracks from the track file. Tracks are eliminated for one of the following reasons:

(i) The track extension test has recently resulted in a coast, slew, or altitude correction too often because matching coordinates in the target reports were not found;

(ii) The target kinematics have become such that the target is no longer of interest (e.g., outside the coverage volume or turned outbound, etc.);

(iii) The track has been dismissed because it has been determined not to be a real target (e.g., a phantom target).

J.1.5.1 Eliminating Tracks with Poor Extensions

The basic idea here is to assign a confidence index to a track as a function of the track parameters and to retain or eliminate tracks as a function of the behavior of this index. Confidence begins at zero and increases as "good" data comes in. The confidence counter saturates at some level and stays there

as long as the data stays good. Imperfect data will decrement the confience count, and when it reaches a certain low level (not necessarily zero) the track is eliminated and its file space is made available for other tracks.

The various tests on the track can cause different size increments or decrements; it is not the purpose here to design a full confidence algorithm, but merely to identify a set of appropriate tests which could be involved in the algorithm.

When one or more points on a track is coasted in extension, this is evidence of a certain amount of mismatch between the track and the new target report. For each coasted coordinate, a certain confidence decrement can occur. Thus, an extension in which both range and bearing are coasted decrements the count by more than one which coasts only range.

Extensions involving a bearing slew can also decrement the count, possibly by a lesser amount than for a coast. In the case of slew rate limit violations, the confidence count must be handled carefully A succession of slews of opposite polarity could correspond to bearing swings caused by garble which will eventually be averaged out and will ultimately not perturb the measured track greatly. To prevent a succession of such slews

from causing the confidence count to continually decrease, the polarity of the first slew can be stored and only subsequent slews in the same direction will decrement the count; those of opposite polarity will increment it. A long string of alternating slew violations certainly is an indicator of interference, and could be an input to the algorithm which determines when to raise the active garble flag.

A third factor which can effect confidence count is altitude correction. If is not immediately obvious how to treat this. Certainly a succession of track points requiring altitude correction is a garble indicator, but it may also be the case that the garble environment is "clearing up," that is, the changes that are occurring arise from two superposed replies that are separating and will enventually not overlap. Thus, it is recommended that any rule for governing confidence count based on altitude correction also include range information, perhaps as follows.

If a track shows a high enough altitude correction ratio over some interval exceeding a minimum length, then a portion of the track file should be searched to find all other tracks within the same beam which have either (i) a range coordinate indicating overlap with the altitude-corrected track (less than 20.3 μs differential round trip time), or (ii) a high altitude correction

ratio. If a track is found which has both (i) and (ii), the differential range rate between the two targets is computed (difference in the two $\dot{r}$ coordinates). This range rate will indicate whether the tracks are actually separating in range; if they are, the tracker should be lenient in decrementing the confidence count of either track, since it appears that both tracks are real and are simply garble victims at the current time. If, however, no other track within garble range shows altitude fluctuations, then the original track is probably suspect and its confidence should be permitted to decrement.

J.1.5.2 Elimination of Kinematically Uninteresting Tracks

There are three general ways in which a real track becomes kinematically uninteresting:

(i) The range goes beyond 20 nmi (outside the protected volume);

(ii) The range rate becomes positive (outbound target);

(iii) The altitude differential becomes excessive (target is too far above or below BCAS to be a potential threat).

Testing for each of these conditions is relatively straightforward. In each case, one parameter of the test ought to be specified, which is the time that the tested parameter e.g.

range in (i), exceeds the appropriate threshold. A track is eliminated when any of the three stated parameters exceeds its threshold for the stipulated time.

J.1.5.3 Elimination of Phantom Targets

One kind of phantom target is a false track generated by garbled altitude codes of two or more aircraft on the ground, e.g. at an airport, which indicate an airborne target. Detection of phantoms is investigated in detail in Appendix I.3, where two solutions to the problem are outlined. In one, the component of target velocity along the BCAS-to-target range vector is observed over a period of time, after which it is decided whether the evolution of that component corresponds to a moving or a stationary target. The alternative approach is to use data in the track file to generate instantaneous estimates of the target airspeed; targets consistently yielding an airspeed estimate below that possible for an airborne platform (e.g., 50 knots) are eliminated. Only vehicles such as VTOL's or helicopters could inadvertantly be eliminated by this test.

When all the above procedures have been completed, the target report file and track file for the given interrogation are updated and ready for the next inputs. The track file is opened to the Conflict Detection and Resolution Algorithm to update the threat status.

This concludes the supplement detail on the active mode reply processor and tracker.

J.2 Semi-Active ATCRBS/RBX Mode

This mode has a few features not found in active mode. The first is processing of passive replies, which involves the use of coordinate frames other than (r, β, z). A second feature is the use reply runs in generating target reports. The third is the mix of active and passive data in forming tracks. Each of these is dealt with in the appropriate place in the following.

J.2.1 Track Initiation

In this and the following discussion we will assume that at least one target in the singular region of the single site RBX solution is to be tracked, as that will force consideration of the mix of active and passive modes.

J.2.1.1 Target Reports

Target reports are generated separately for the active and passive data. In fact there are two active reports being generated here, but one of those is the result of interrogating the RBX for range-to-site and data, and is thus input to the Radar Tracker. Thus we will assume that BCAS range-to-site is available from the Radar Track File whenever needed. The other active report comes from interrogating the target, just as in pure active mode. The structure of that report is just as given in Section 1 of this Appendix.

The passive report is obtained differently. When the ATCRBS beam passes the target, a series of replies will be generated (a reply run). When these are received at BCAS, the run must be processed for differential time of arrival (DTOA) and target differential azimuth. Both of these computations involve centermarking the beam, and as a result the passive raw data file is much larger than its active counterpart.

A portion of the Raw Data File is allocated for replies to each mainbeam interrogation. The stored data for each reply is the bracket pair arrival time, and the ID (or altitude, depending on the interrogation mode). Each section of reports, for a given mainbeam interrogation is labeled with an ACP index, indicating beam position at time of transmission.

Generating a passive target report mainly depends on locating and processing reply runs. In the roughly 2.5 ms between interrogations, the target and the BCAS can only move a few feet, corresponding to a few nanosecond of change in arrival time and differential delay. Since the pulses are 0.45 μs long, there is almost no perceptible change in the garble environment over a reply run of 8-16 replies. Nonetheless, there is garble resolution information available in the returns.

Identification of a reply run is easy without garble. Replies to the different interrogations are correlated on the basis of arrival time. Arrivals should be within a few

nanoseconds of one another.* A string of replies lying within the arrival time window can be termed a reply run if it satisfies certain conditions. The ATCRBS reply processor has a rather involved algorithm for detecting reply runs. The BCAS algorithm can be simpler, and can be stated as follows:

(i) The run length must be between a stipulated minimum and maximum;

(ii) The run need not be solid -- single replies may be missing, but not two or more consecutive ones;

(iii) Beginning and end of the run are defined by two or more missing replies.

Without garble, the ID codes in the Mode A replies should never change across the run, and altitude should vary at most in one digit when the aircraft is near a transition altitude. Other changes in altitude or ID are garble-induced, and the Target Report Generator can attempt to process them out. Garble can enter the middle of a reply run if a second target within the beam but at a different azimuth begins to reply. Since the most likely perturbation to the code

---

*/ If BCAS were flying an outbound radial, and the target were inbound on the same radial, both at Mach 1, DTOA of 5 ns would be measured.

is the insertion of extra pulses, the altitude or ID code which is the logical "and" of the individual codes is the best code estimate for the reply run.

When there are, for example, two targets at the same DTOA but different azimuths, the end of one reply run overlaps the beginning of the second. The azimuth "end effect" described above can be used to separate the two. On a Mode C reply, for example, three altitude codes would sequentially occur. The first would be true code for Target 1, the third true code for Target 2. In between a garble region would occur, most likely generating the logical "or" of the two codes. The leading edge of the garble region marks the beginning of reply run #2, and the trailing edge marks the end of reply run #1.

A full azimuth end effect algorithm is flagged as an issue in process of resolution (Section 8).

Once reply runs are determined, the runs are center-marked to generate the DTOA and differential azimuth for the target report.

J.2.1.2 Correlation of Target Reports

J.2.1.2.1 DTOA and Azimuth Correlation

Target reports are accumulated over a set of mainbeam passages. Some time after each passage, the Track Initiator looks at the files of active and passive reports for the most recent four passages (interrogations for active), to form new tracks. When geometry dictates that semi-active tracks are to be formed, tentative tracks based on range only are formed from the active data; the procedure used is exactly as described in Section 1. Simultaneously, tentative tracks in DTOA (t) and differential azimuth (α) are formed. In garble, the DTOA is likely to be the more reliable coordinate of the two, because the azimuth data depends upon garble resolution in locating reply run barriers. Thus the passive track is set up for active mode, as follows:

(i) The DTOA correlation is performed analogously to range correlation in the active mode; and

(ii) The azimuth correlation is performed analogously to bearing correlation (Case 4: Four Bearing Points) in the active mode.

(Case 4 in the active mode bearing track formation is the case in which all four target reports have bearings attached).

J.2.1.2.2 Altitude and ID Correlation

Altitude and ID are present in both the active and passive data. Correlation in active mode has been described previously (Section 1.1.2). In passive mode, altitude and ID correlation should be much easier and more reliable than in the active case, because the azimuth end effects will give at least a few clear replies in all but the worst garble situations. Logical anding of the codes will suffice for track initiation. No altitude rate is computed at this point.

J.2.1.3 Correlation of Active and Passive Tentative Tracks

At this point, a set of active tentative tracks and a separate set of passive tentative tracks have been formed. These must be meshed into a single new track list before further tracking can proceed. Of course, if the mode is passive-only at the moment, there are no active tracks to merge. Thus only the semi-active situation is of interest here.

The method of testing the two tentative track files will depend upon the solution which Geometric Reconstruction would use for the corresponding target. This is illustrated by one example.

Assume that BCAS is more than 20 nmi from the RBX, so that the semi-active solution is used everywhere. A rough

estimate of target position can be made from the passive data alone, from which an estimate of the target range can be obtained. Going through the active data file, only Mode Reports showing ranges lying within a window about the rough range are accepted to be paired with the passive points. The size of the window for this comparison can be a function controlled by the geometric logic of the mode. Obviously targets whose range vector is perpendicular to the instantaneous beam direction can have a small range window, while for those in the same beam as the BCAS, the window must be quite large, or another comparison method must be used. At the expense of additional processing complexity, active bearing can be used in the correlation procedure.

For the geometry under consideration, passive altitude and ID are more reliable than active and should be given preference in the correlation.

J.2.2 The Track File

New tracks formed in Track Initiation go to a New Track Buffer to be held for Merge. Target Reports generated by the coalescing of Mode Reports are ready to be tested against existing tracks in the Track File for Track Extension, to be described in the next section.

There are two Track Files in the processor. One is the Master Track File inwhich track data is stored in the preferred (r, β, z) frame. The second, the Mode Coordinate Track File, has tracks stored in Mode Coordinates to ease the Track Extension tests.

J.2.3 Track Extension

The initial phase of track extension is performed in the <u>mode coordinates</u>. These are the natural coordinates for the data which is measured, in this case, r, t, α, and z. This is to avoid performing coordinate conversations to the standard (r, β, z) frame on unsmoothed data. Procedured for range matching were outlined in the Active Mode section of the appendix, and the same techniques apply here; t and α are extended as r and β were in active mode.

Next, Geometric Reconstruction converts the track into standard (r, β, z) coordinates. This is smoothed with one of the αβ filters and stroed in the Master Track file.

J.2.4 Track Merge

Following Track Extension, Track Merge is performed. First the new track/old track merge is performed, and second the old track pair merge tests are performed. In deciding which track pairs to test, only tracks whose ACP indices are within a two beamwidth limit ever need to be tested.

J.2.5 Track **Elimination**

Track **elimination is based in part on the Confidence** Index which is generated in Track Extension. The criteria are exactly the same as in Action Mode. However, due to differences in data rate and geometry, the weighting factors on each increment or decrement may differ, as may the levels set in for saturation and track rejection.

The kinematic criteria are the same as in active mode. Large range, diverging range rate, or large altitude differential will result in elimination.

While may phantom tracks may be eliminated by failing confidence, the specific phantom addressed in Appendix I can be tested for. This is the phantom which is created by garble altitude codes from aircraft on the ground. Since such replies will only be generated on the active replies, their occurrence should be far less frequent in this semi-active mode.

J.2.6 Preparation for Next Track Update

Once the Master Track File is cleared of any tracks to be eliminated, some updating is done to prepare for the next extension. Each track in the Master File is converted back to mode coordinates by an inverse of the geometric reconstruction logic formulas. The inverse formula may differ from one track to the next as a function target position (moving out

of a singularity, for example). The full set of mode coordinates must be regenerated even if they are redundant, because these match the coordinates in which target reports will be presented for extension.

The first step of $\alpha\beta$ filtering, the prediction step, is performed next, and the predictions are saved in their own file. Upon receipt of the next set of target reports, these predicted points are fed back into Track Extension, and the cycle described in this section repeats.

This concludes the single RBX site semi-active mode reply processor descripiton.

APPENDIX J - REFERENCES

J.1 Clark, J.S., "Active Beacon Collision Avoidance System Computer Algorithms-ATCRBS Mode," MTR-7280, MITRE Corporation, McLean, Virginia (August 1976).

J.2 R.J. McAulay, "The Effects of Interference on Monopulse Azimuth Estimation Accuracy," ATC Working Paper 42 WP-5002, M.I.T. Lincoln Laboratory, Lexington, Massachusetts, (7 March 1973).

J.3 Orr, R.S., J.E. Evans, and S.J. Dolinar, "The Effects of Slew-Rate Limiting in the Phase II TRSB Receiver."

APPENDIX K

BCAS COLLISION AVOIDANCE ALGORITHMS

K-1. OVERVIEW

This section describes a basic set of BCAS collision avoidance algorithms designed to operate in both the active and the passive modes. The algorithms have been kept general enough to permit the use of several display types. In addition, an interface with the ATARS ground based collision avoidance system has been presented. No logic has been defined specifically for a semi-active mode of operation as the required algorithms would not differ substantially from those defined.

The logic has been designed to support three types of commands, positive ''do'', negative ''don't'', and vertical speed limit commands. In addition, two types of Intruder Position Data (IPD) messages are provided--flashing IPD's and ordinary, non flashing IPD's. The logic also supports a third type of IPD in which the bearing of the intruder is known, but the relative altitude is unknown. A method for coordination for command selection is provided to guarantee that BCAS command selection will be compatible with commands displayed by the intruder and with any commands already in the aircraft display. Although the method of coordination has been designed to work with both ATARS and BCAS originated commands, the exact method of reselection of an incompatible command in a multi aircraft environment has not yet been provided.

The logic presented here can drive three types of cockpit displays. The first is the Airborne Collision Avoidance System (ACAS) display which is used with the logic contained in Reference 1. The second is the baseline Intermittent Positive Control (IPC) display described in Reference 2. The third display is a general purpose Plan View Display (PVD) which can present a pictorial plan view of intruder aircraft in the vicinity of the protected aircraft in an own-aircraft-centered and own-heading--oriented framework.

In this document only skeletal logic has been provided for certain elements of the BCAS

interface. In particular, the logic required to drive the display has not been specified. Also, the interface has been provided for the multiple aircraft logic responsible for choosing a complementary command when the initial command is rejected; but the logic itself has not been provided.

Figure K-1-1 shows the relationship of the BCAS logic to the other parts of the airborne system. The Surveillance Processor receives and decodes messages addressed to this aircraft and surveillance replies. ATARS Messages and BCAS Coordination Messages are directed to the Coordination Function described in Appendix L. Raw target reports are correlated with tracks by the surveillance processor and BCAS target reports are issued into the Surveillance Report Buffer. The BCAS logic reads reports out of these buffers and performs resolution of any potential conflicts. In this process the BCAS logic may be required to coordinate with other aircraft or to determine systems responsibility. To do this, BCAS sends messages to the Coordination Function. BCAS writes commands and IPD's into the Display Request Queue and the DISPLY routine reads the queue and updates the Display List. The display Driver translates the vectors in the Display List into lights on the CAS display.

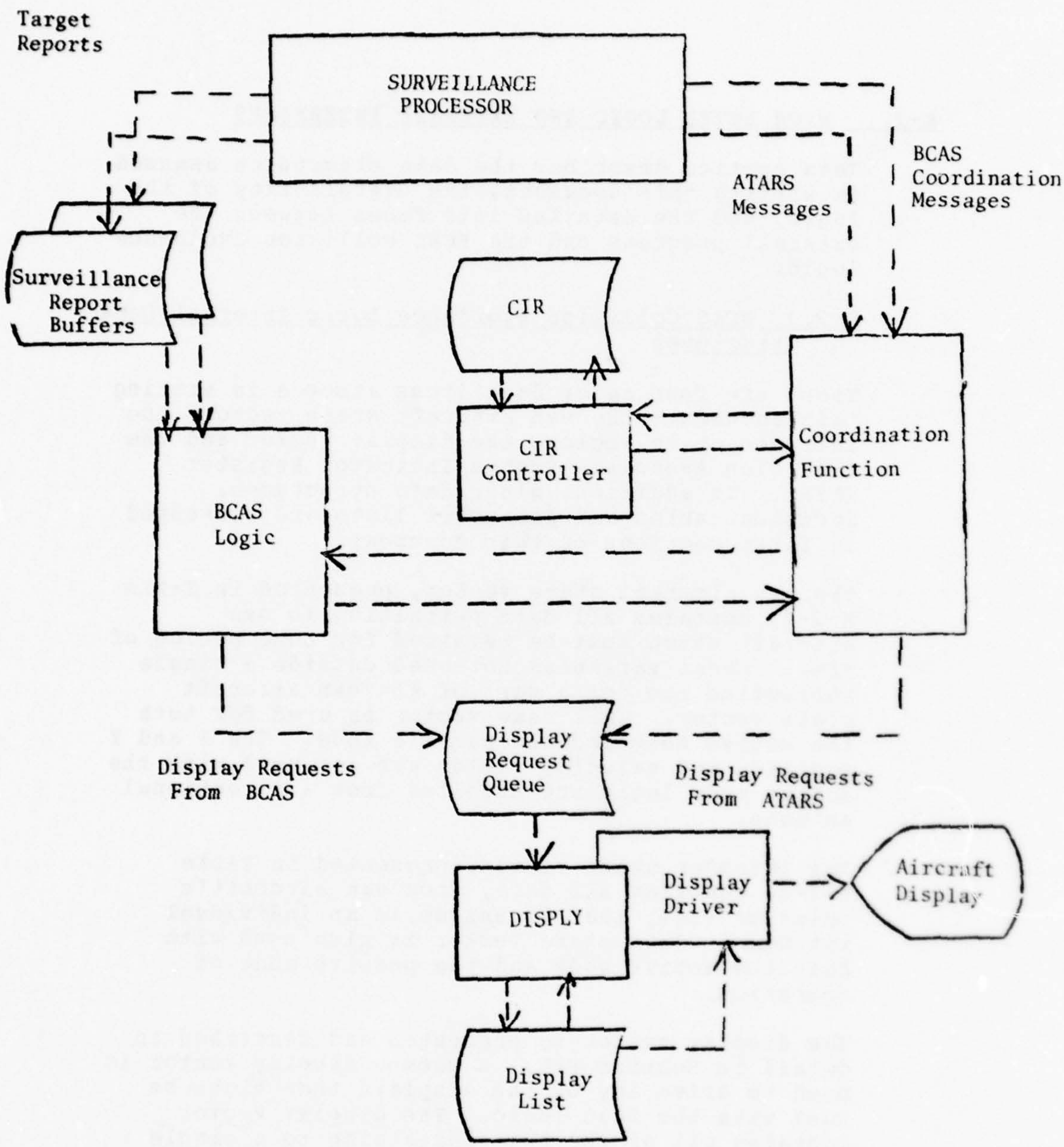


FIGURE K-1-1. THE BCAS LOGIC INTERFACES WITH THE COLLISION AVOIDANCE SYSTEM.

K-2. HIGH LEVEL LOGIC AND EXTERNAL INTERFACES

This section describes the data structures assumed in writing this document, the overall flow of the logic, and the detailed interfaces between the external programs and the BCAS collision avoidance logic.

K-2.1 BCAS Collision Avoidance Logic Internal Data Structures

There are four major data items assumed in writing this document--the own aircraft state vector, the intruder state vector, the display vector and the Collision Avoidance System Indicator Register (CIR). In addition, minor data structures, decision tables and parameter lists are presented in later sections of this document.

The own aircraft state vector, presented in Table K-2-1, contains all data pertaining to own aircraft which must be retained for some period of time. Local variables not used outside a single subroutine are not a part of the own aircraft state vector. This same vector is used for both the active mode and the passive mode. The X and Y position and velocity fields are not used with the active mode logic are supplied from a directional antenna.

The intruder state vector, presented in Table K-2-2, contains all data, from own aircraft's point of view, that is unique to an individual intruder. This state vector is also used with both the active mode and the passive mode of operation.

The display vector is presented and described in detail in Section K-6. A common display vector is used to drive any of the displays that might be used with the BCAS logic. The display vector contains all of the data pertaining to a single intruder that would be needed to drive a display. Data for several intruders can be displayed simultaneously to own aircraft. In this case, a separate display vector will exist for each intruder.

TABLE K-2-1

OWN AIRCRAFT STATE VECTOR

SYMBOL	UTILIZATION
IDOWN	Identification of own aircraft
XOWN YOWN ZOWN	Own aircraft tracked position coordinates (Passive Mode Only)
XDOWN YDOWN ZDOWN	Own aircraft tracked velocity coordinates (Passive Mode Only)
TDATA	Time for which the tracked position and velocity coordinates are presented
SLEVEL	Desensitization level indicator
RTRANS	Range of own aircraft from the closest ground transponder used for desensitization
INDEX	Index corresponding to desensitization level used for entering the 3 x 2 matrix of values for the settable parameters

TABLE K-2-2

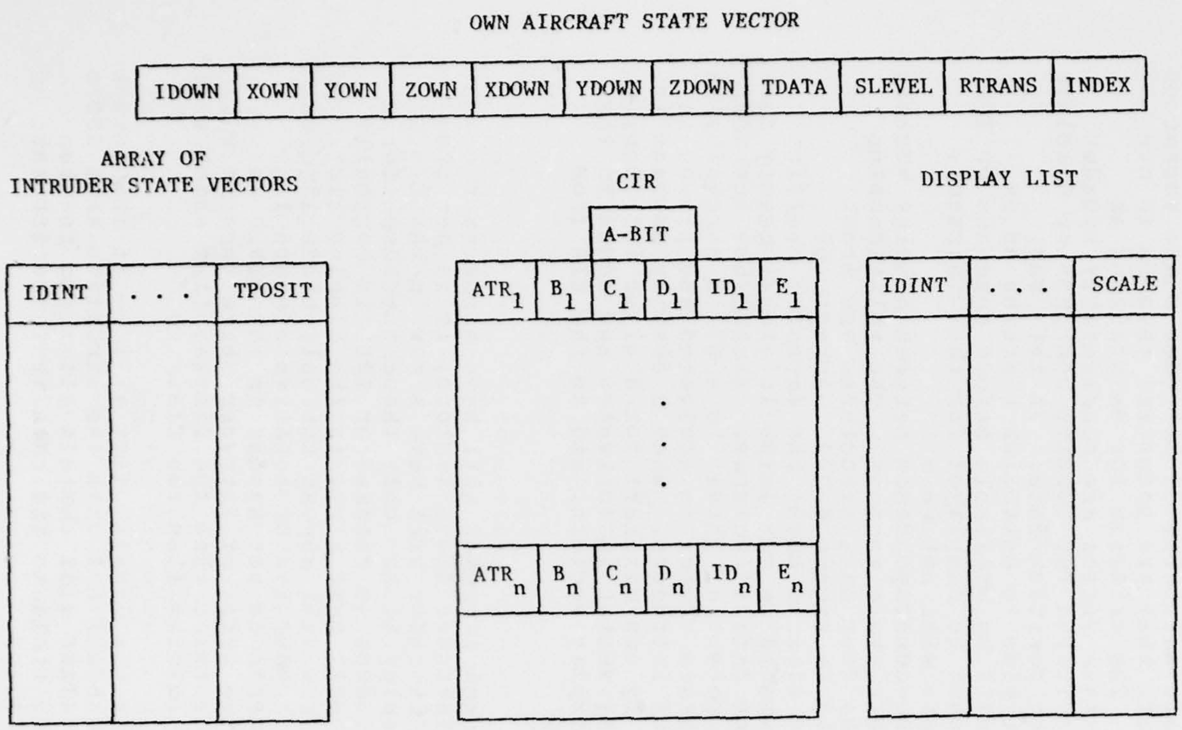
INTRUDER STATE VECTOR

SYMBOL	UTILIZATION
IDINT	Identification of the intruder
TINT YINT ZINT	Intruder's tracked position coordinates (X & Y for passive mode only)
XDINT YDINT ZDINT	Intruder's tracked velocity coordinates (X & Y for passive mode only)
R	Tracked range to the intruder
RD	Tracked range rate of the intruder
TDATA	Time for which the tracked position and velocity coordinates are represented
TREPT	Time of the last set of target reports for this intruder
BC	ATARS/BCAS Control Variable
KHIT	Own intent status indicator with respect to this intruder
JNDEX	Index corresponding to intruder's equipage used for entering the 3 x 2 matrix of values for the settable parameters
FLASH	Flag indicating whether own aircraft has a flashing IPD for this intruder
CMDSAV	Command being displayed to own aircraft due to this intruder (Coding is the same as DPLY but value may be different from DPLY)
NTENT	Own A/C intent with respect to this intruder
TPOSIT	Time at which DPLY is set to a positive command

Own aircraft maintains an intruder state vector on all aircraft that are potential threats to own aircraft. The criteria for maintaining an intruder state vector are considerably broader than the criteria for issuing commands or displays of intruder position data. In this way, sufficient time to establish tracking on an intruder will be available before commands or IPD messages must be displayed for that intruder. Hence, there will not be a one-for-one-correspondence between display vectors and intruder state vectors. The relationships between the four data structures are shown pictorially in Figure K-2-1. Arrays of sufficient size to cover the expected traffic scenario should be set aside in global memory for each of the data structures. When a new intruder becomes a potential threat to a given aircraft, an intruder state vector is activated and placed in the list of intruders. When a display message is generated by own airc aft for a given intruder, a new display vector is activated and added to the list of display vectors, and to the CIR (for commands).

Although each intruder will have a row in the Array of Intruder State Vectors, it is not true that each intruder will have a row in the CIR or in the Display List. Only those intruders for which a message (a command or IPD) is currently displayed will have a row in the display list. In the CIR a row will appear for only those aircraft for which a positive or negative command is active. IPD's do not appear in the CIR. In general, the Array of Intruder State Vectors will have more entries than the Display List which will have more entries than the CIR.

Messages in the display list will be in the format shown in Table K-6-1 with the exception that IPD's issued by ATARS will contain all zeros in the intruder ID field to indicate that the IPD was issued by ATARS.



NOTE: REFER TO ATARS/BCAS COORDINATION REPORT FOR DEFINITION OF ENTRIES IN THE CIR.

FIGURE K-2-1

BCAS DATA STRUCTURES

In addition to the three data structures written by BCAS, a buffer containing the surveillance reports received during the BCAS cycle will also be read by the BCAS logic.

K-2.2 High Level Organization

The call to the BCAS routine is supported by the surveillance processor and the display driver. When a surveillance report is received, the report is decoded and buffered by the surveillance processor. During each BCAS cycle the logic will read the buffer to see what reports have been received since the last BCAS cycle. The logic takes a report from the buffer and performs aircraft tracking in the routine TRIPAS. The surveillance processor is responsible for buffer management and the BCAS logic uses the information in the buffer to update it's Array of Intruder State Vectors.

The Display Routine and the display driver operate at the other end of the BCAS logic. The routine reads requests from the Display Request Queue and writes vectors into the Display List. The Display Driver translates the vectors found there into signals which light the appropriate display. The structure of this driver will depend on the type of display used.

At several places in this document, two sets of flow charts are presented for the same subroutine--one for use with the active mode logic and one for use with the passive mode logic. Although for clarity they have been separated here; it is left to the discretion of those coding the BCAS logic as to whether the subroutines should be coded separately and one selected at subroutine call time, or whether a union of the code from the two sets of flow charts should be coded as a single subroutine with enbedded tests to bypass unnecessary logic.

Once per BCAS cycle the own aircraft state vector will be updated by the BCAS tracking routine BTRACK. Although this routine is referred to as a

tracking routine tracking in the x, y coordinate system really does not take place here. Rather, BTRACK receives current x, y coordinates and current x, y rates as input. The tracker smooths the altitude report to estimate the actual altitude.

In addition to updating the own aircraft state vector the tracking routines perform the important function of adapting the BCAS parameters to the airspace. This level of adaptation can be specified by the ground ATC or can be determined dynamically by the BCAS logic itself. A further description of this procedure is given in Section K-7.

The routine BCASDT represents all of the logic to be performed by the BCAS collision avoidance logic upon receiving a report from an intruder that has been determined to be in potential conflict with own aircraft. A high level flow chart of this routine is presented in Figure K-2-2. Only the high level flow is presented here. Individual tasks are represented as subroutines and are described individually in other sections of this document.

The BCASDT routine performs intruder tracking, threat detection and resolution, limit command determination, IPD determination and display functions. Interfaces are provided to coordinate BCAS with ATARS. The program tests various option switches to determine which command and display options have been selected. The selectable options are summarized in Table K-2-3. Except for PAFLG, NOHOR, and NOHPOS, the option is selected if the switch is set equal to 1 and not selected if the switch is set equal to zero. The operational values for these switches have been specified in Table K-2-3.

The program initially sets the display indicator to "no command" (DPLY = 0). The first test in this routine is performed to see if the BCAS logic has been disabled by the ground ATC system. This is indicated by SLEVEL = 4. If so, some

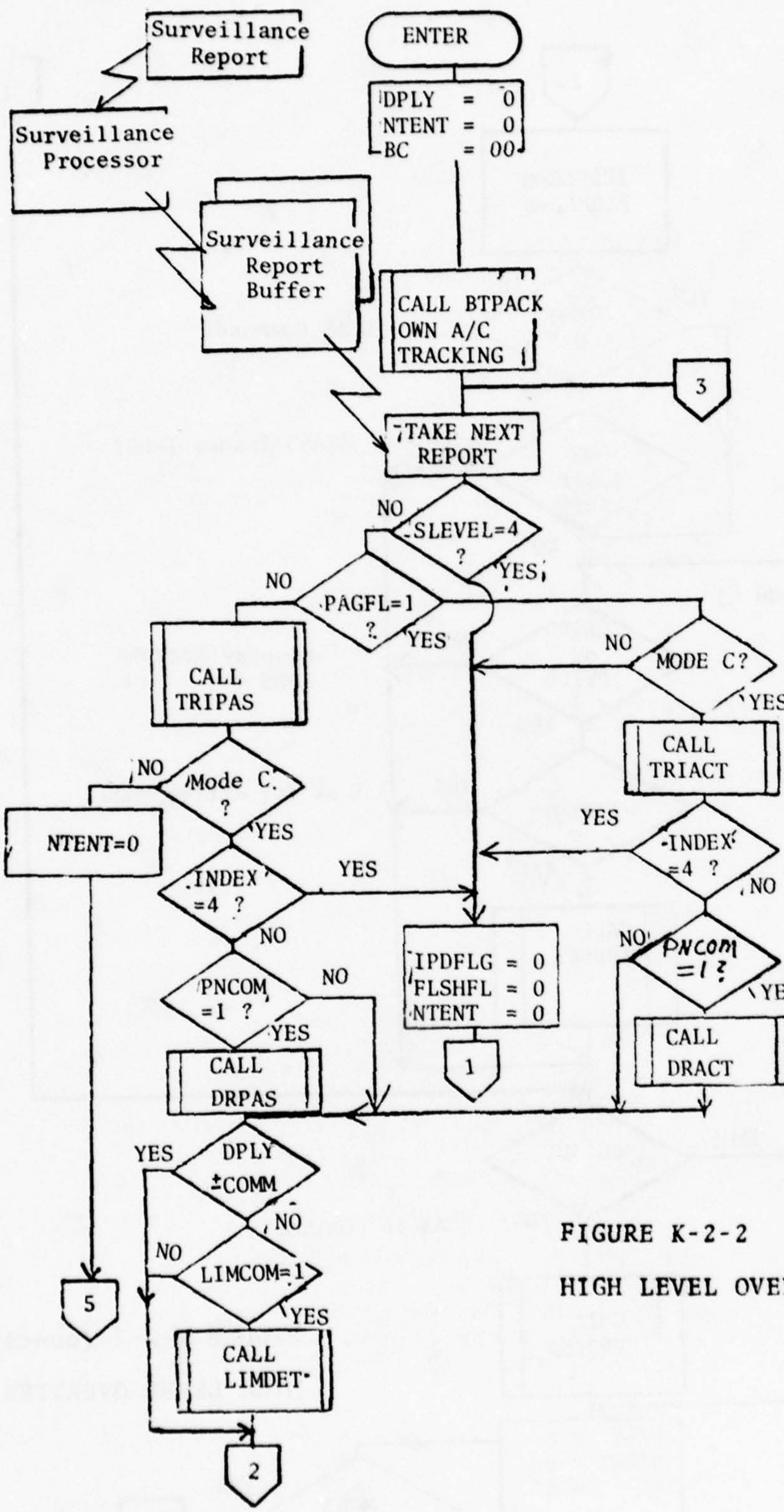


FIGURE K-2-2

HIGH LEVEL OVERVIEW

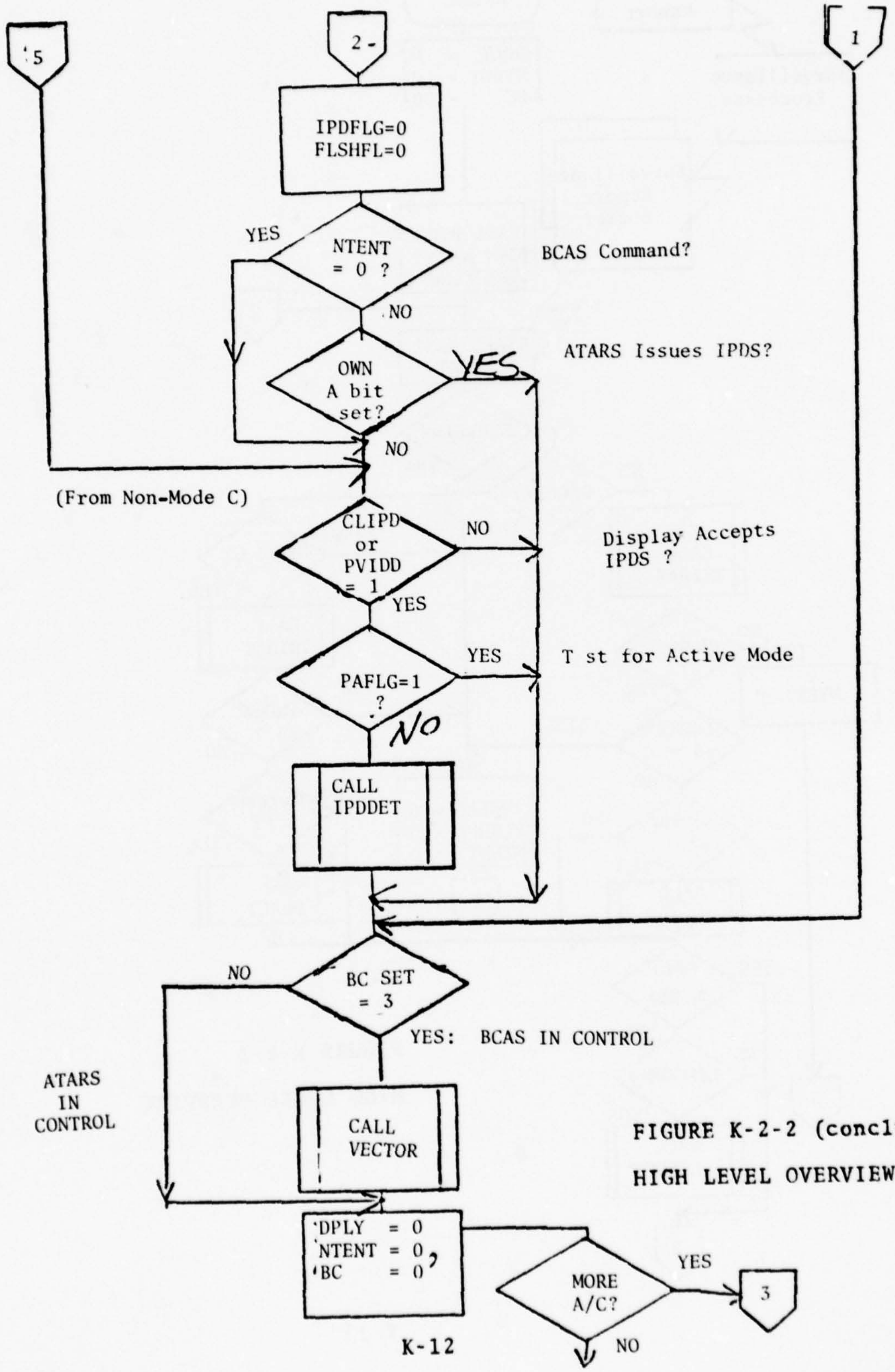


FIGURE K-2-2 (concluded)

HIGH LEVEL OVERVIEW

TABLE K-2-3

SELECTABLE DISPLAY AND LOGIC OPTIONS

OPTION	SWITCH	OPERATIONAL VALUES
Positive and Negative Commands	PNCOM	1
Passive or Active CAS Logic	PAFLG	Varies
(0 = passive) (1 = active)		(0, 1)
Limit Commands	LIMCOM	1
Horizontal Commands	NOHOR	0
(0 = horizontal commands are allowed)		
Positive Horizontal Commands	NOHPOS	0
(0 = horizontal positive commands are allowed)		
Clock/Relative Altitude IPD Data	CLIPD	1
Plan View IPD Data	PVIPD	1

control variables are initialized and only the display vector subroutine is called so that any BCAS activity that might have existed previously would be deleted. It is expected that setting SLEVEL=4 would be exercised only at 1 or 2 miles from an airport. The BCAS logic would be shut off to avoid nuisance alarms from stationary aircraft on the airport or from aircraft in VFR visual patterns at the airport.

If SLEVEL is not equal to four, the BCASDT routine calls TRIPAS to track the intruder's data and then proceeds to determine the type of command, if any, which should be displayed. The program then tests INDEX to determine whether BTRACK has disabled the BCAS logic. If INDEX = 4, the program then tests PNCOM to determine whether positive and negative commands have been selected. If so, the program then calls DRACT or DRPAS to perform the threat detection and resolution functions. Here BCAS to BCAS and BCAS to ATARS coordination is performed to guarantee selection of compatible commands and to determine system responsibility. Multiple aircraft conflicts are resolved by branching to an as yet undefined multiple aircraft logic. The logic sets the display indicator DPLY to the desired display code. Regardless of whether or not the detection and resolution have been bypassed, BCASDT tests DPLY to see if it is set to either a positive or a negative command. If so, the limit command logic is automatically bypassed.

If the limit command logic is entered, further tests are made to determine the type of limit command, if any, that should be displayed; and the display indicator DPLY is set accordingly. Next, the program resets the control variables, IPDFLG and FLSHFL and then tests to see if the IPD and vector logic should be entered. Command vectors are written only for those aircraft under BCAS control (e.g. BC = 3). Depending on the display options selected, the VECTOR routine computes the display vector and loads it into the display request queue. This list is subsequently used as input to the display routine which writes vectors into the Display List. The Display Driver

periodically reads the vectors in the Display List and lights the appropriate symbol on the aircraft display.

Multiple IPD's and commands may result from the several display vectors in the Command Display List. Examination of the CIR during command selection will have insured the compatibility of display vectors containing positive, negative or limit commands.

The BCAS logic has been designed to interface with the ATARS system through the CIR-controller coordination function described in Appendix L. This interface sets the priorities of the systems so that, in general, ATARS has priority over BCAS in providing commands to pairs of conflicting aircraft within the ATARS airspace. Whenever two or more CIR-equipped aircraft are in conflict within ATARS airspace, ATARS will issue IPD's and commands to provide collision protection for that pair of aircraft. BCAS provides additional coverage around the edges of ATARS airspace by protecting against pop-up intruders. The coordination between BCAS and ATARS is carried out in a pairwise manner through the CIR's of the conflicting aircraft.

When an intruder not equipped with a CIR is encountered, this coordination cannot be carried out. Unless an ATARS message has already been issued for this aircraft BCAS cannot tell if the intruder is inside or outside of ATARS coverage. BCAS must then assume that this is a pop-up intruder and determine the appropriate BCAS command. The frequency of this occurance is limited by two factors that in practicality guarantee ATARS priority. First, all BCAS IPD's are suppressed within the ATARS airspace. This gives ATARS additional time to recognize the conflict and take action. Second, the BCAS parameter settings can be automatically adjusted within ATARS airspace to give even more time for ATARS to assume control of conflicts involving unequipped intruders.

K-2.3 BCAS Logic External Interfaces

This section summarizes all external interfaces to the BCAS logic. BCAS receives inputs from several sources. Correlated target reports are extracted from the surveillance report buffer in the format shown in Table K-2-4 and used in TRIPAS to update the intruder track record. Own altitude reports and x and y rates are required from own aircraft (although in the relative coordinate system absolute x and y coordinates are not required). The CIR controller provides inputs to the BCAS logic in response to coordination requests. These inputs consist of a compatible command and a BCAS/ATARS responsibility variable. The command is translated into a display vector and displayed to the pilot, provided that the responsibility vector indicates that BCAS is in charge of the conflict. Finally, the BCAS logic requires two external inputs. These are the current clock time, TCUR, and the sensitivity level, SLEVEL, from the ATC.

The BCAS logic provides outputs to three sources. The primary output is the vector written into the Display Request Queue for eventual display to the pilot (see Section K-6). A secondary output consists of messages to be sent to the ground ATC. These are provided through the Coordination Function which sends own aircraft's CIR to the ground on every DABS sensor scan and this information can be used by ATC if desired. The final output of the BCAS logic consists of the messages to the CIR controller. These messages are sent to the controller when the BCAS logic wishes to initiate coordination and presents the Coordination Function with a provisional command (the variable NTENT) and the intruder ID(IDINT), when own aircraft A bit is requested, and when ATCRBS track updates are provided to the coordination function.

The BCAS logic processes an intruder only when it finds a target report in the Surveillance Report Buffer. The surveillance processor must provide BCAS with target reports. A hit (RPTFLG = 1) is

TABLE K-2-4

REPORT TO BCAS LOGIC FROM SURVEILLANCE PROCESSOR

VARIABLE NAME	INTERPRETATION
IDINT	ID of the intruder A/C
XRINT	Relative x-coordinate report of intruder A/C
YRINT	Relative y-coordinate report of intruder A/C
ZRINT	Absolute z-coordinate (altitude) report of intruder A/C
RR	Relative range to intruder A/C
EQ	2-bit intruder equippage indicator 00 ⟶ ATCRBS 01 ⟶ DABS w/o display 10 ⟶ DABS w/ display 11 ⟶ BCAS only the A/C equipped with BCAS is referred to as equipped for desensitization purposes
PAFLAG	1 ⟶ this track maintained in active mode
DFLAG	1 ⟶ drop this track
RPTFLG	Report flag = 1 if surveillance report received = 0 if track coasted

provided when the surveillance processor correlates raw target reports with own track. A miss (RPTFLG = 0) is provided when the surveillance processor receives no correlatable raw report when expected. When BCAS receives a miss the track of that particular aircraft is coasted.

Special action need not be taken when a new intruder first begins to satisfy the potential conflict criteria. The BCAS logic will recognize that no track previously existed for this aircraft and will start a track in the Array of Intruder State Vectors based on the target report. Conflict detection and resolution will begin after two target reports have been received. Similarly when a conflict ceases to exist an intruder will be dropped from the Array of Intruder State Vectors upon receipt of a drop command from the Surveillance Processor. Initiation and termination of intruder tracks takes place in the tracking routine TRIPAS.

Table K-2-5 summarizes the external interfaces of the BCAS logic. The variables in the calls to BTRACK and the variables in calls to TRIPAS, are described in Section K-7. PAFLG is determined by the type of surveillance report received and is passed to the BCAS logic so that the proper version of the resolution routines can be selected. If PAFLG indicates high quality x, y data acceptable for choosing commands, XRINT and YRINT will contain data but RR will be empty. For low quality data RR will contain relative range.

A description of the display vector can be found in Section K-6. See Appendix L for a further description of the interface with the CIR Controller through the coordination function.

TABLE K-2-5

INPUTS AND OUTPUTS OF THE BCAS LOGIC

INPUTS

- EXTERNAL

  TCUR SLEVEL

- FROM OWN A/C

  IDOWN RTRANS ZOWN ZDOWN YDOWN ZDOWN

- FROM THE SURVEILLANCE REPORT BUFFER (INTRUDER A/C)

  IDINT RPTFLG XRINT YRINT ZRINT EQ RR PAFLG DFLAG

- FROM THE CIR CONTROLLER COORDINATION FUNCTION

  OWN "A" BIT BC NTENT

OUTPUTS

- DISPLAY REQUEST QUEUE

  IDINT BC AUD COMACT CLKACT CLOCK RELACT
  PVACT RANGE BEAT ALT EQ SCALE

- CIR CONTROLLER

  1) IDINT NTENT EQ
  2) "A" BIT REQUEST
  3) ATCRBS TRACK UPDATE

K-3. DETECTION AND RESOLUTION LOGIC FOR POSITIVE AND NEGATIVE COMMANDS

This section presents the threat detection and resolution logic that is used to determine positive and negative commands. Two separate routines are employed to select the best command; when the PAFLAG indicates that the x, y data received from the surveillance processor is of high quality the DRPAS routine selects the best positive or negative horizontal or vertical command. When lower quality x, y data is received (as indicated by PAFLAG) DRACT selects the best positive or negative vertical command. The DRPAS logic is presented first (Figure K-3-1) and is described in some detail. Since the DRACT logic is largely a subset of this it is then easily understood.

Note that DPLY is set to zero before entering the positive/ negative command logic. The output of this subroutine is conveyed by DPLY. If no positive or negative commands are required, DPLY remains zero. Otherwise, DPLY represents the command to be displayed according to the coding presented in Section K-6-3. A mapping NDPLY between the value of the variable NTENT, own aircraft intent, and the value of DPLY has also been provided here.

Coordination among BCAS equipped aircraft and between the BCAS and ATARS Systems is provided during the command determination phase by the CIR controller interface function. Commands, said to be provisional upon selection by the BCAS logic, are passed to the CIR controller for coordination with commands already in the own aircraft display, and with commands in the display of the threat aircraft. The controller returns a compatible command to the BCAS logic. In the simple two aircraft scenario this involves only verification that the command selected by BCAS does not conflict with any commands already displayed in either aircraft. An unspecified multiaircraft logic called by the CIR Coordination Function is assumed to be able to handle the case of command conflict.

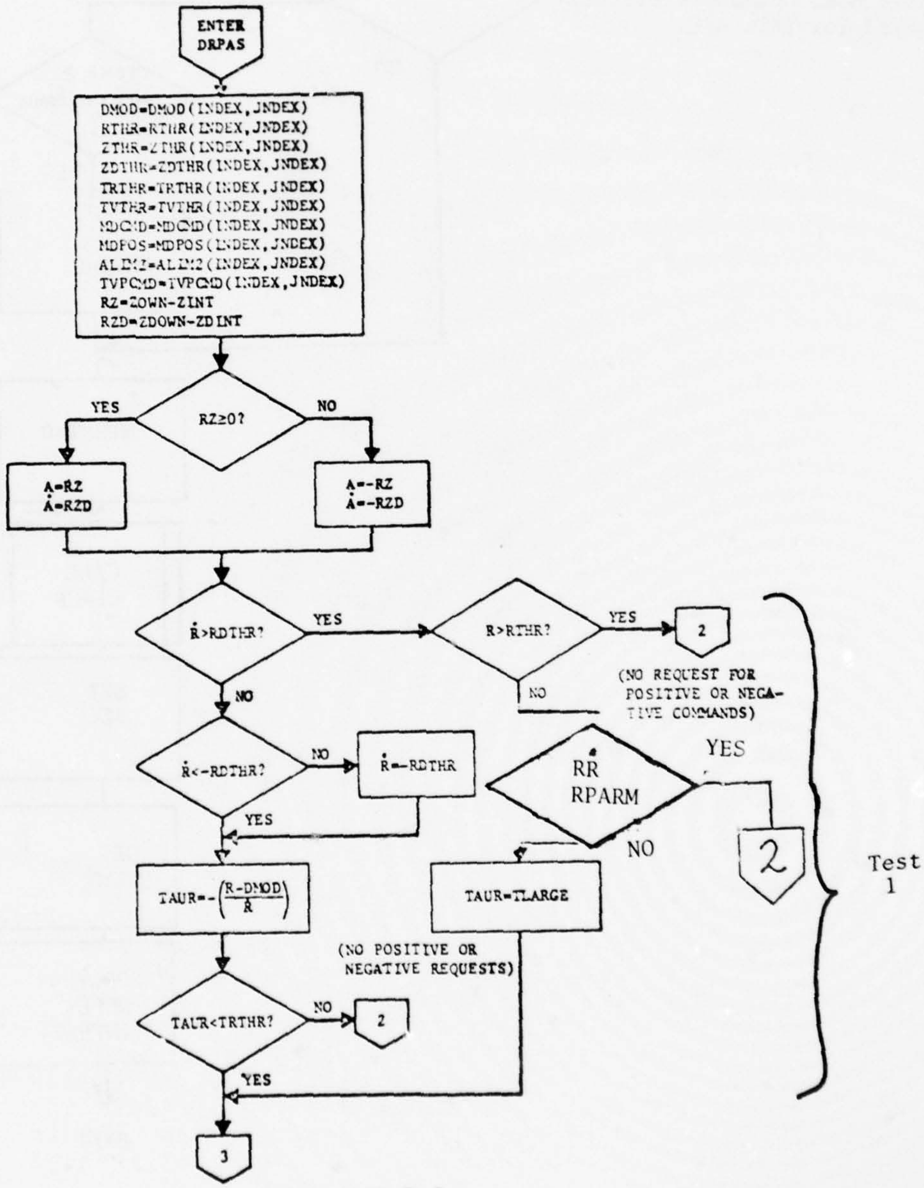


Figure K-3-1

DETECTION AND RESOLUTION LOGIC FOR POSITIVE AND NEGATIVE COMMANDS – PASSIVE MODE

No positive or negative command requested for this A/C.

Positive BCAS Command Previously Displayed for this A/C.

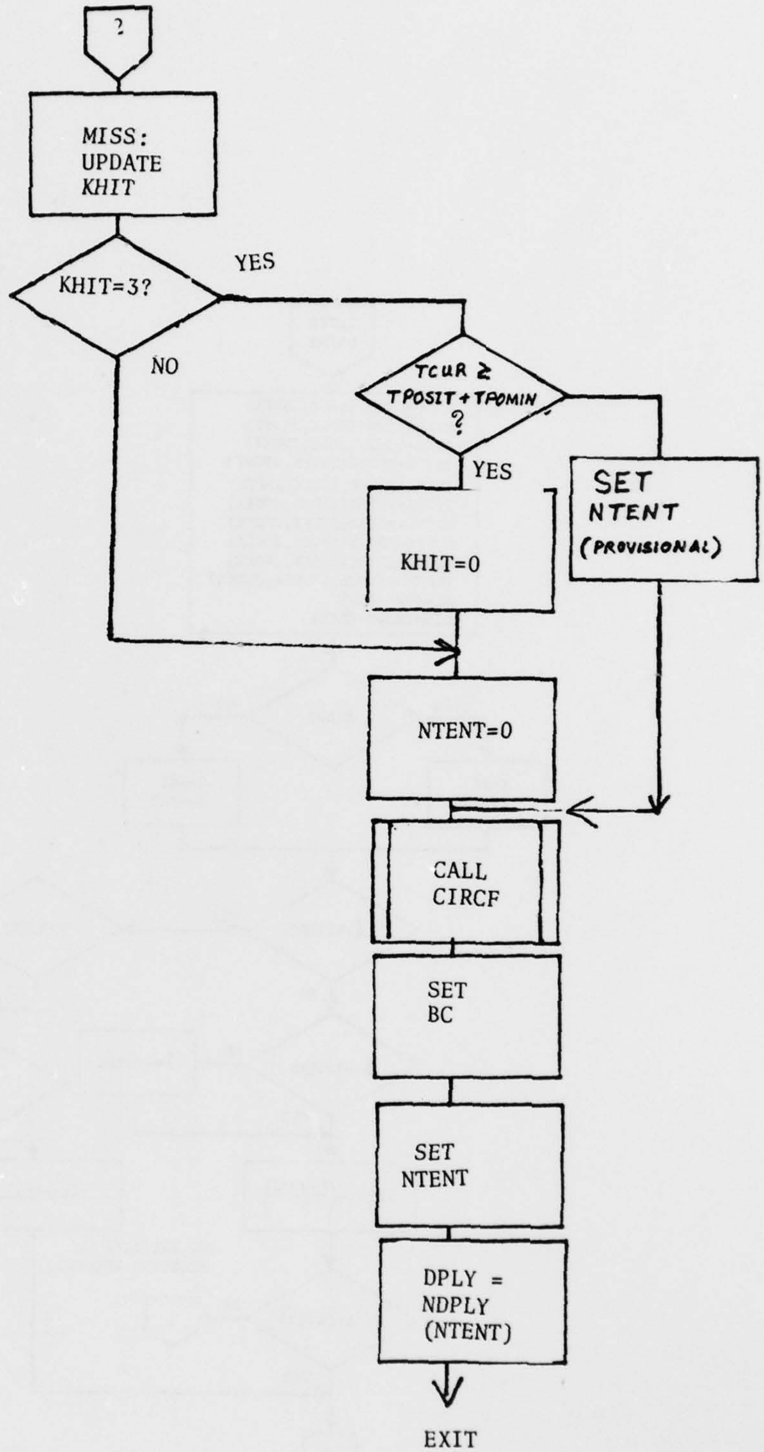


Figure K-3-1 (Continued) Detection and Resolution for Positive and Negative Commands -- Passive Mode.

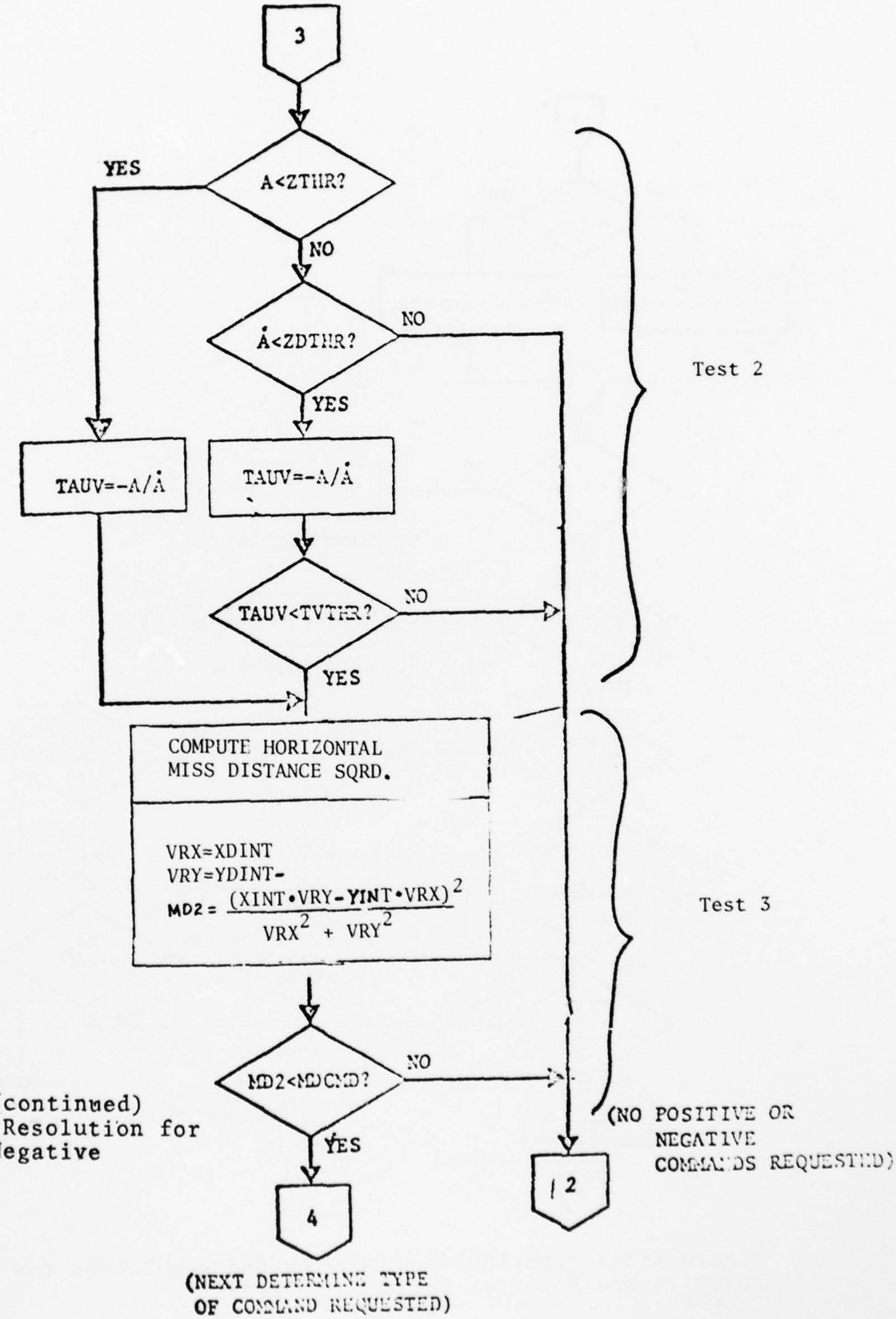


Figure K-3-1 (continued)
Detection and Resolution for
Positive and Negative
Commands

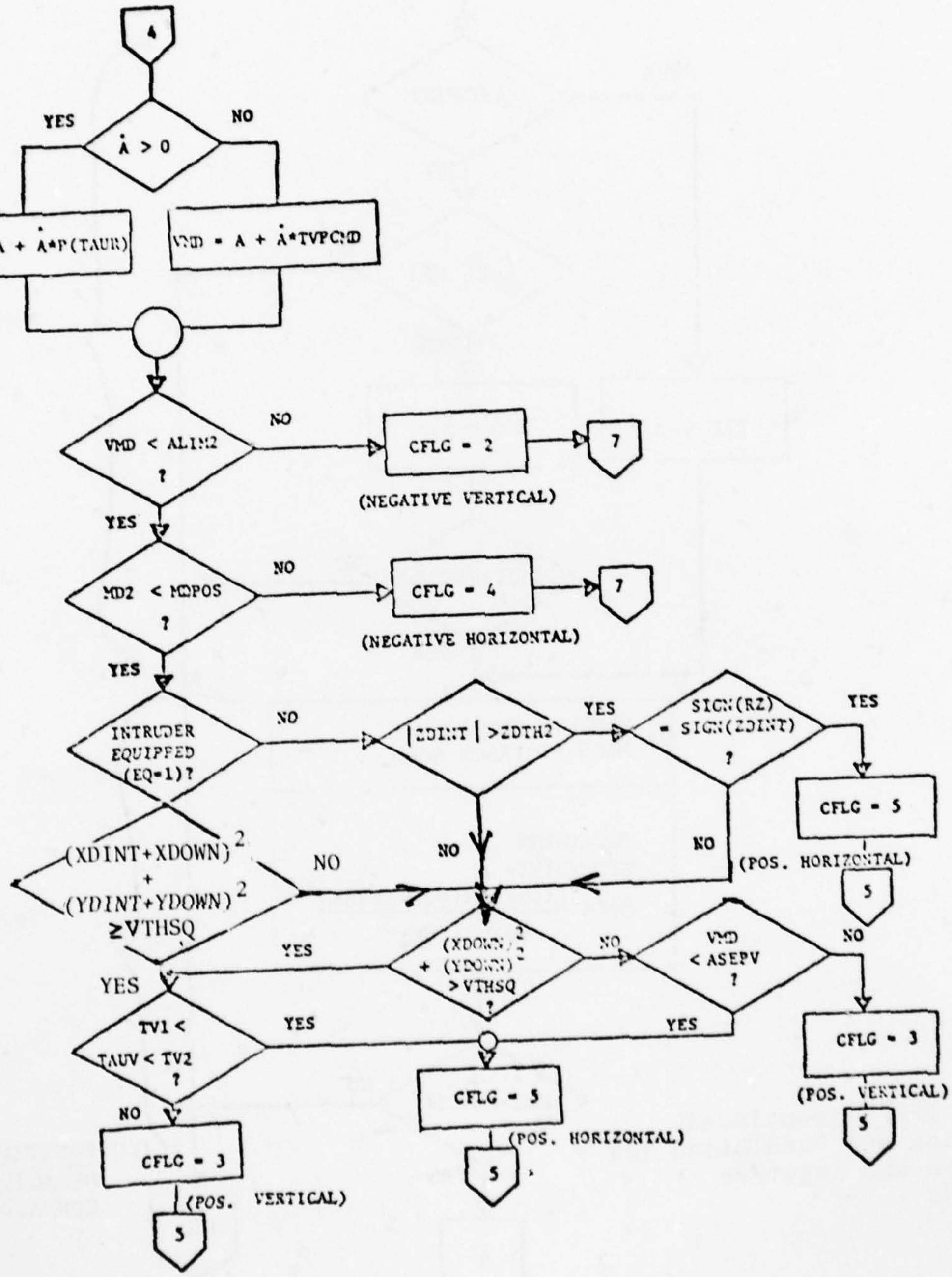


Figure K-3-1 (continued) Detection and Resolution for Positive and Negative Commands DRPAS-

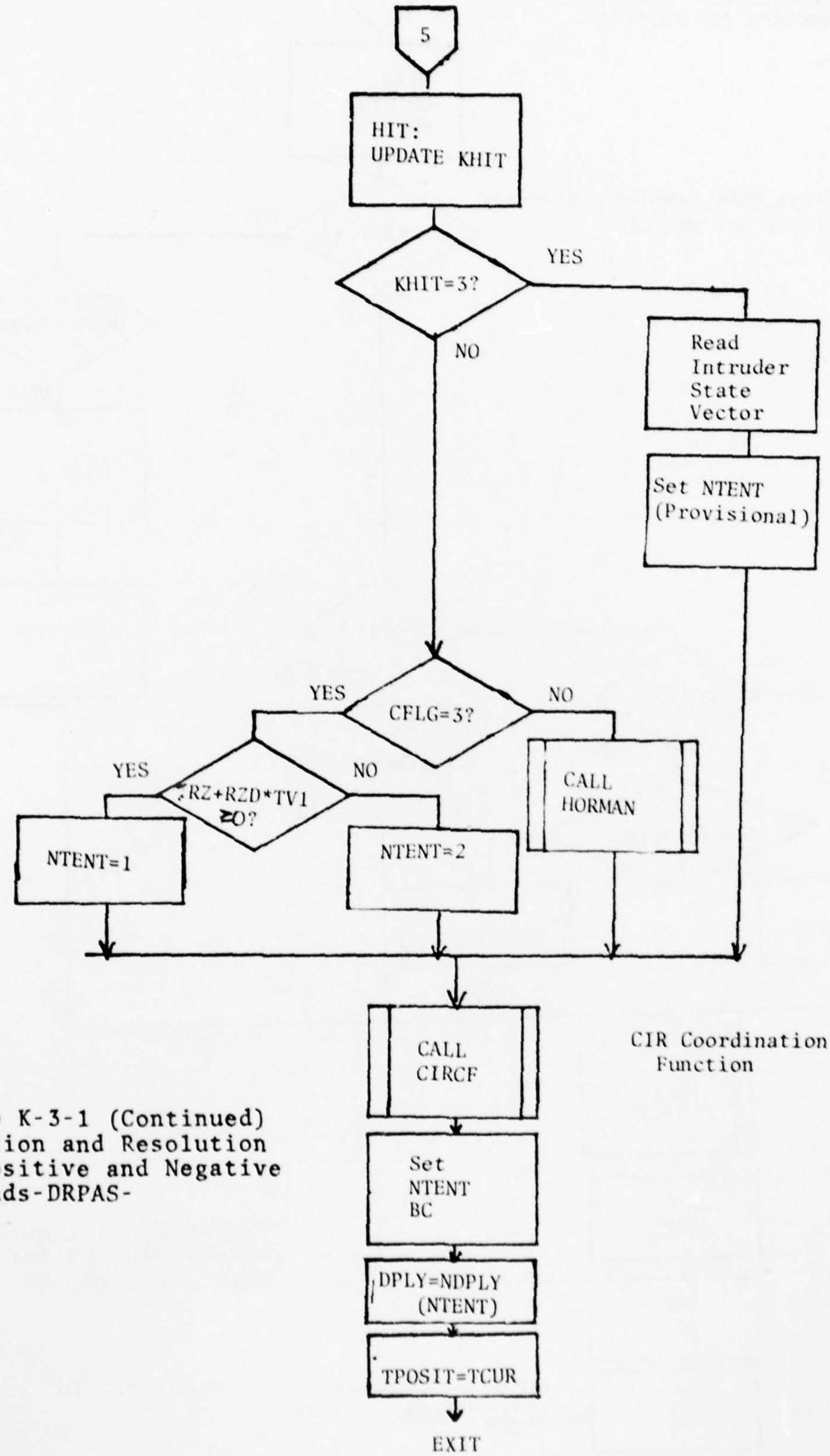


Figure K-3-1 (Continued)
Detection and Resolution
for Positive and Negative
Commands-DRPAS-

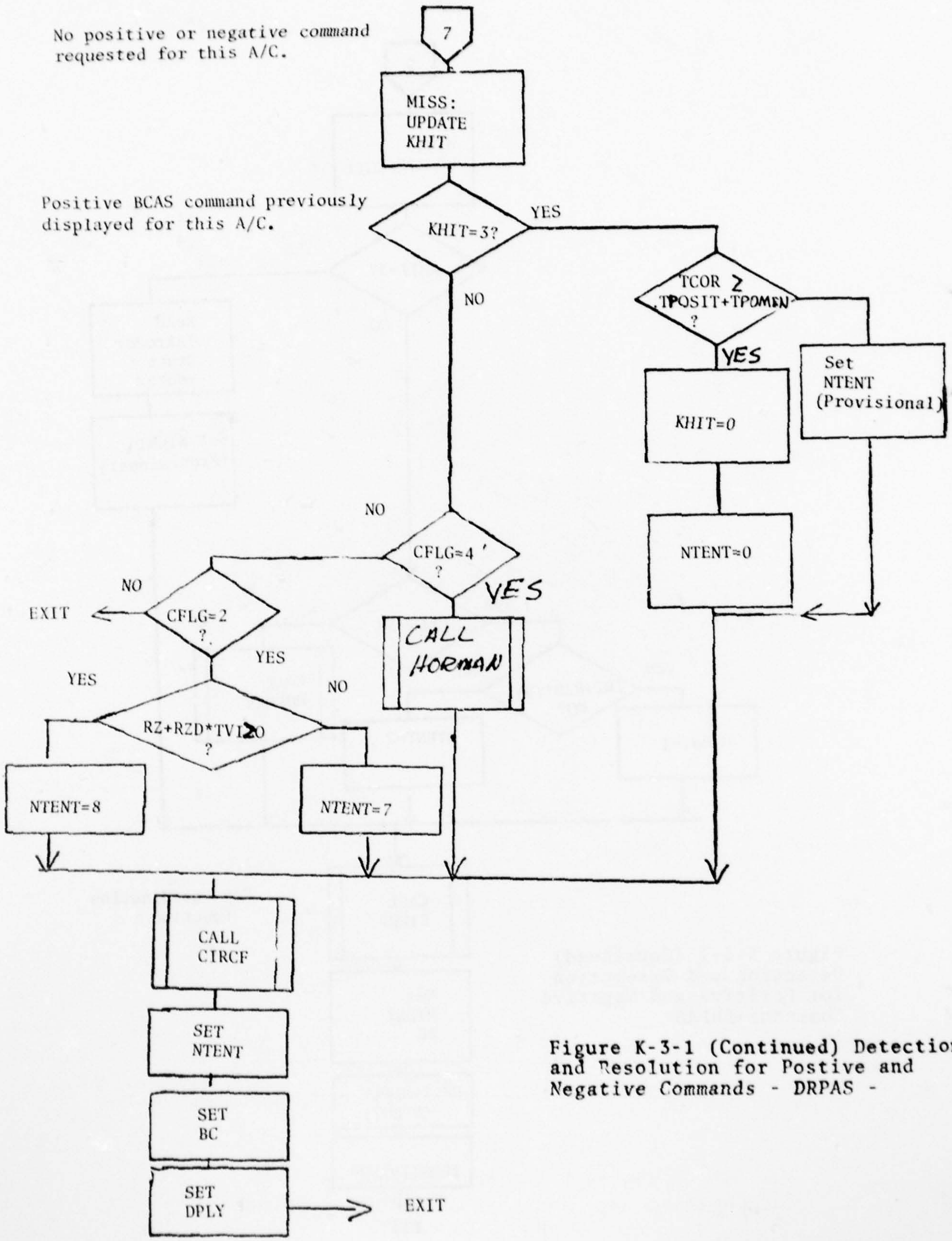


Figure K-3-1 (Continued) Detection and Resolution for Postive and Negative Commands - DRPAS -

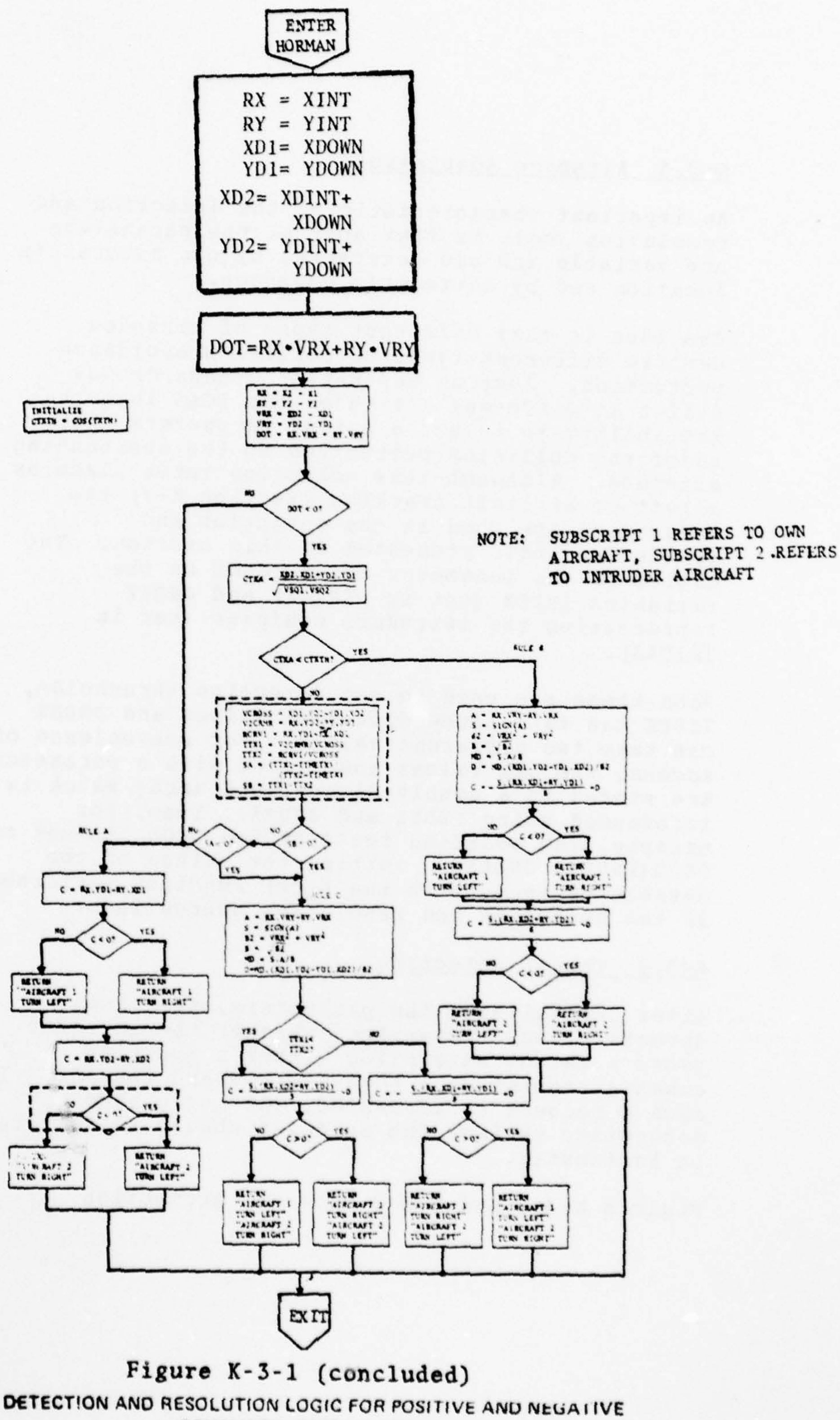


Figure K-3-1 (concluded)

DETECTION AND RESOLUTION LOGIC FOR POSITIVE AND NEGATIVE COMMANDS--PASSIVE MODE

K-3.1 Airspace Adaptation

An important characteristic of the detection and resolution logic is that most of the parameters are variable and are determined by own aircraft's location and by intruder's equipage.

The idea is that different types of airspace deserve different types of collision avoidance protection. Just as separation standards now differ at different altitudes the BCAS logic has the ability to select a set of parameters that adapt the collision protection to the surrounding airspace. Although this selection takes place as a part of aircraft tracking (Section K-7) the parameters are used in the detection and resolution logic presented in this section. The choice of the parameter set depends on the variables INDEX (set in BTRACK) and JNDEX representing the intruders equipage (set in TRIPAS).

When these are used to set detection thresholds, INDEX can take three different values and JNDEX can take two different values. For convenience of access, the six values associated with a parameter are stored in a doubly-dimensioned array which is referenced using INDEX and JNDEX. Thus, for example, the modified tau distance DMOD, is set to DMOD(INDEX, JNDEX). Setting the values of the setable parameters is the first function performed in the detection and resolution subroutines.

K-3.2 Threat Detection

After initializing the parameters, the threat detection logic determines whether the intruder poses a threat warranting either a positive command request or a negative command request. If such a request is warranted, the logic also determines whether the maneuver should be vertical or horizontal.

Figures K-3-2 and K-3-3 show the protection

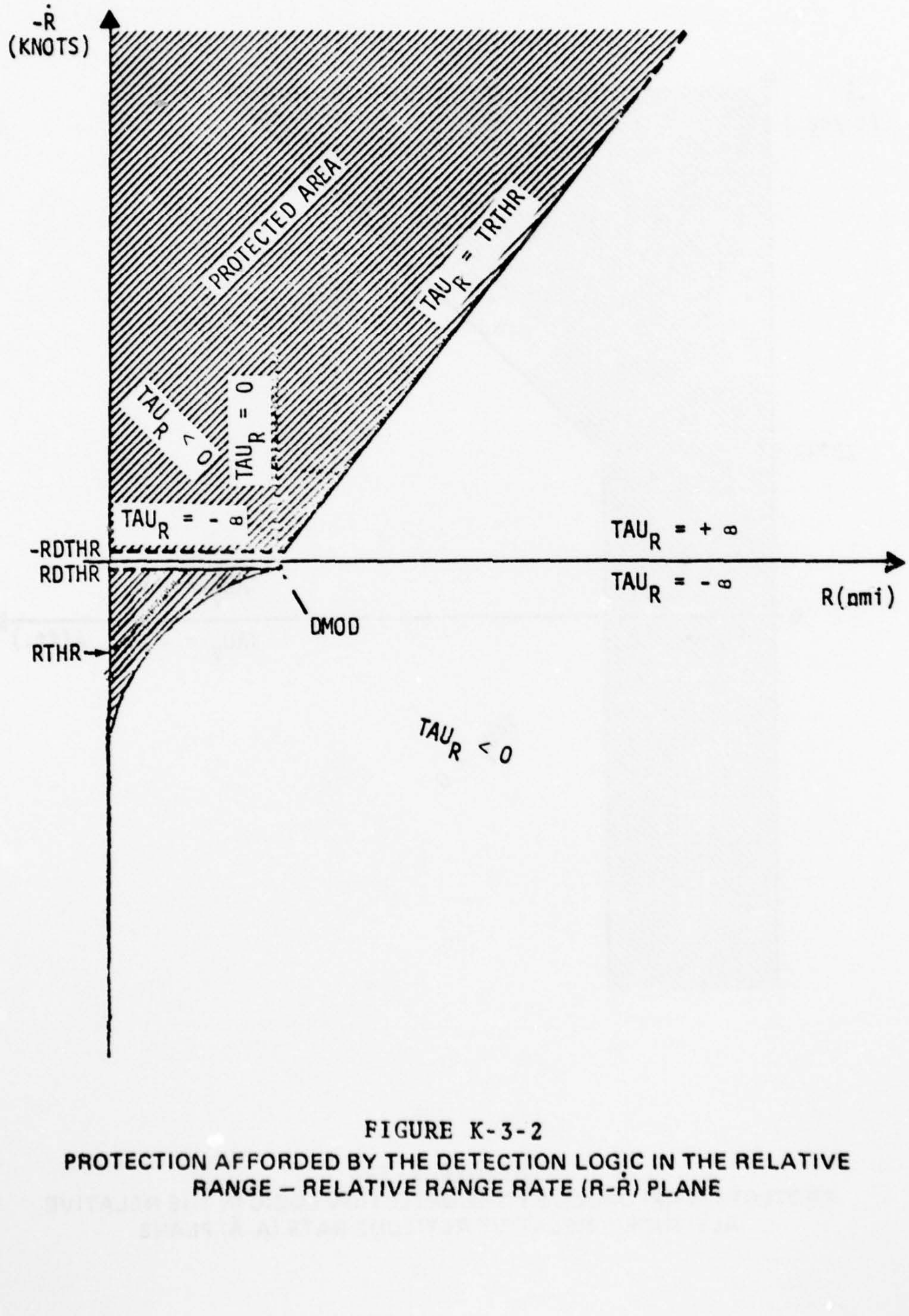


FIGURE K-3-2
PROTECTION AFFORDED BY THE DETECTION LOGIC IN THE RELATIVE RANGE – RELATIVE RANGE RATE (R-Ṙ) PLANE

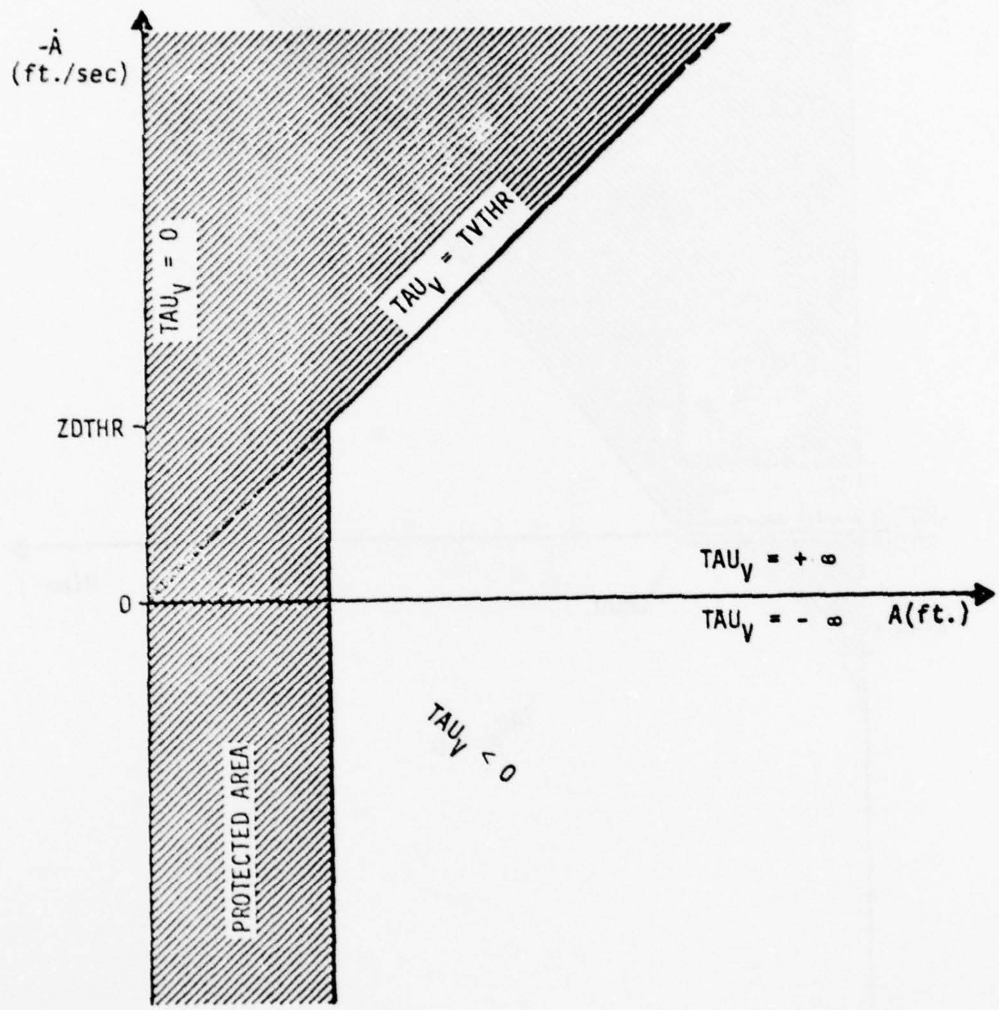


Figure K-3-3
PROTECTION AFFORDED BY THE DETECTION LOGIC IN THE RELATIVE ALTITUDE – RELATIVE ALTITUDE RATE (A-Ȧ) PLANE

afforded by the logic in the relative range--relative range rate plane and in the relative altitude--relative altitude rate plane, respectively.

A command is requested by the logic when the following three conditions are satisfied simultaneously:

1. the relative range and relative range rate are such that the point defined by the pair lies within the protected area in the R-RDOT plane,

2. the relative altitude and altitude rate are such that the point defined by the pair lies within the protected area in the A-ADOT plane, and

3. the projected horizontal miss distance is less than a certain threshold.

As shown in the flow chart, the first condition involves either a modified range-tau test or an immediate range test. The second condition involves either a vertical-tau test or an immediate altitude test. Finally, the third condition is tested by computing the square of the horizontal miss distance (MD2) and comparing it to the threshold MDCMD.

If all three conditions are satisfied, the logic proceeds to determine the type of command to be requested. This involves deciding whether the maneuver should be vertical or horizontal and whether the command should be positive or negative.

As shown, the logic requests a negative vertical command if the vertical miss distance VMD is greater than the limit ALIM2. The program sets VMD to the projected miss distance A + ADOT * P(TAUR) A if the aircrafts are vertically separating* (i.e., if A > 0) and to the linear projection A + ADOT * TVPCMD if the aircrafts are vertically closing. Note that, if ADOT < 0, VMD

will be negative if the product of the rate ADOT and the time TVPCMD is larger in magnitude than the current separation A (indicating that a vertical crossing occurs in the TVPCMD interval). If VMD > ALIM2, the program sets CFLG = 2, thereby requesting a negative vertical maneuver, and then exits the detection logic to process the request.

However, if the vertical miss distance is smaller than the limit, further tests are made to determine the type of request. From here, the logic will select either a positive or a negative horizontal maneuver or a positive vertical maneuver. If MD2, the square of the horizontal miss distance is greater than an acceptable value, MDPOS, a negative horizontal command is selected. If it is less than this value a positive command (vertical or horizontal) must be selected.

From here the flow chart shows different paths for equipped and for unequipped intruders. For intruders not equipped to do coordination the vertical rate is checked against a threshold. If it is greater than ZDTH2 and a check of the signs indicates that the intruder is closing then a positive horizontal command is requested. Otherwise, a test is made of the square of our own (horizontal) speed. If this is greater than VTHSQ a positive vertical command is normally requested. If, however, the vertical tau indicates that a coaltitude condition would occur at about the same time that the aircraft would begin to maneuver, a positive horizontal command is requested instead. If our own (horizontal) speed is smaller than VTHSQ, a horizontal command is normally requested. However, if the vertical miss distance is nearly as great as the desired threshold, a vertical command is selected.

When the intruder is equipped, the intruder's (horizontal) speed is considered in addition to

---

* The predictive function P is defined in Section 8.

own speed. If either aircraft has speed greater than the threshold, vertical is selected, unless the previously mentioned coaltitude condition would occur at about the time of maneuver. If both aircraft are slow, horizontal is selected, unless the vertical miss distance is near the desired threshold.

K-3.3 Positive Command Requests

As just seen, one possible output of the detection logic is a request for a positive command. The logic for processing such a request is shown immediately following the detection logic. It determines whether and when a positive command is displayed.

If a positive command was displayed on the previous scan (i.e., if KHIT = 3) the program calls the CIR controller coordination function with the value of NTENT equal to that found in the intruder state vector for this aircraft. The CIR coordination function sends an interrogation message to the threat aircraft, refreshing his display, returns the compatible command, (the same value of NTENT) and the value of BC, the B and C bits from the CIR row, determining the system responsible for separation assurance. This coordination guarantees that an ATARS originated command will be maintained until cancelled by ATARS or until BCAS no longer detects a conflict and ATARS coverage has ceased. But if no positive command was displayed, the logic is more complicated. The logic for initially displaying a positive command requires that the command be requested on two consecutive scans or on two scans separated by a third. Furthermore, in the case of an intruder, equipped with a CIR the logic calls the CIR Coordination Function to determine whether the positive command requested is compatible with any displayed by the intruder.

The variable KHIT is used to implement the two-out-of-three logic for initially displaying a positive command. KHIT is initially set to zero when the aircraft state vector is created and

updated after each hit (i.e., request for a positive command) and after each miss (i.e., no request) according to the rules shown in Table K-3-1. The four integer values that can be assumed by KHIT are explained in Table K-3-2. Note that KHIT = 3 indicates that the two-out-of-three condition has been satisfied and that positive commands are displayed. The NTENT register codes corresponding to these commands are shown in Table K-3-3.

From here, intruders not equipped with BCAS, ATARS or even DABS are handled in the same manner by the BCAS logic. The CIR controller is called to determine ATARS or BCAS System responsibility.

K-3.3.1 Equipped Intruder Case

For the purpose of coordinating positive commands, and determining ATARS/BCAS System responsibility each BCAS or ATARS display equipped aircraft is provided with a CIR. The CIR acts as a central repository for command information; it contains integer codes describing commands currently displayed to the pilot. The Coordination Function (Appendix L) provides the interface between the BCAS collision avoidance logic and the CIR. It receives provisional commands from the BCAS logic and returns finalized commands to the logic. As shown in DRPAS flowchart the coordination function is explicitly called when a positive command is selected.

K-3.3.2 Unequipped Intruder Case As shown, the processing for the intruder not equipped with BCAS is exactly the same as that for the equipped intruder with the exception that different values of the parameters specified in Section K-8 are used. The Coordination Function must be called to determine BCAS to ATARS System responsibility. Since unequipped intruders do not have a CIR bit the usual manner of allocating this responsibility through examination of intruders 'A' bit does not apply. Rather, ATARS is provided every opportunity to assume control of the conflict

TABLE K-3-1

NEW VALUE OF KHIT AS A FUNCTION
OF OLD VALUE AND HIT OR MISS

	NEW KHIT	
OLD KHIT	HIT	MISS
0	2	0
1	3	0
2	3	1
3	3	3

AD-A061 949 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C OFFIC--ETC F/G 17/7
FAA BCAS CONCEPT. VOLUME III B. APPENDICES F - M,(U)
APR 78 E J KOENKE
UNCLASSIFIED FAA-EM-78-5-III-B NL

3 OF 5
AD
A061949

3 OF 5

AD
A061949

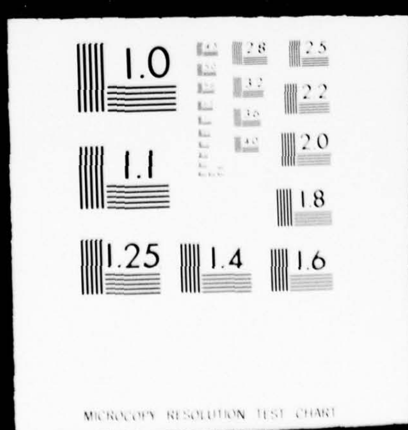


TABLE K-3-2

THE VARIABLE KHIT AND ITS STATES

VALUES OF KHIT	MEANING
0	NO PREVIOUS COMMANDS, NO PREVIOUS HITS
1	A HIT TWO SCANS AGO AND A MISS THE PREVIOUS SCAN
2	A HIT ON THE PREVIOUS SCAN
3	2-OUT-OF-3 RULE HAS BEEN SATISFIED AND POSITIVE COMMAND IS DISPLAYED

TABLE K-3-3

INTENT REGISTER CODES

CODE	MEANING
0	No command selected
1	Climb, intruder descent
2	Descend, intruder climb
3	Own turn left, intruder turn right
4	Own turn left, intruder turn left
5	Own turn right, intruder turn right
6	Own turn right, intruder turn left
7	Own don't climb, intruder don't descend
8	Own don't descend, intruder don't climb
9	Own don't turn right, intruder don't turn left
10	Own don't turn right, intruder don't turn right
11	Own don't turn left, intruder don't turn left
12	Own don't turn left, intruder don't turn right

Note: These commands are the values available to the local variable NTENT and also to the variable D_i in the CIR.

through delay of BCAS processing by selection of the BCAS parameters for the unequipped intruders to be smaller than the ATARS parameters and by suppression of BCAS PWI's when own aircraft is receiving ATARS coverage. These maneuvers allow ATARS to remain the primary system while retaining BCAS protection against pop-ups of unequipped intruders.

K-3.3.3 Multiple Intruder Case

In the case where own aircraft or threat aircraft is threatened by more than one intruder the command must be selected to be compatible with the intent of all intruders. A special register is used to maintain information on the intent of all intruders. This storage location, the CAS (Collision Avoidance System) Indicator Register, or CIR is also used to provide ATARS to BCAS coordination. Its structure is shown in Appendix L.

K-3.4 Processing A Miss

A miss is said to have occurred if the detection logic does not request a positive command. As shown, the variable KHIT, which tracks the hit-miss and display status of positive commands, is updated to reflect the miss and then tested (KHIT = 3) to determine whether a positive command was displayed on the previous scan.

If KHIT = 3, the logic tests whether the command has been displayed for the minimum length of time required, namely, TPOMIN seconds. If not, the program exits with the positive command still displayed. Bit if the current time TCUR > TPOSIT + TPOMIN, KHIT and the intent register are both reset to zero, thereby wiping out the command and re-initializing the two-out-of-three logic described previously.

If KHIT < 3, the intent register is reset to zero and the coordination function is called to delete this command from the CIR. BC is returned to set BCAS responsibility for removing the vector from the display.

Logic similar to that just described for processing a miss is entered when a negative command is requested by the detection logic. This is described in the next subsection.

K-3.5 Negative Command Requests

After processing the miss, the program proceeds to test CFLG to determine whether the detection logic requested a negative command (provided the program did not exit due to a pre-existing positive command). If CFLG = 4, a negative horizontal maneuver (i.e., don't turn) was requested. The direction of the don't Turn is inferred from the positive maneuver selected by the subroutine HORMAN, For example, if HORMAN selects turn right, the display indicator DPLY is set to 14 to indicate don't turn left. If CFLG = 2, a negative vertical maneuver was requested, in which case DPLY is set to one or two to display either a don't climb or a don't descend according to whether the intruder is projected to be above or below own aircraft. The program exits after setting the display indicator to the desired negative command and coordinating through the CIR Coordination Function.

K-3.6 Computation Of Horizontal Maneuvers

The computation of the best pair of positive horizontal maneuvers for the intruder and own aircraft is shown in the flow chart (Figure K-3-1) for the subroutine HORMAN. The logic was borrowed from ATARS, and except for initialization of variables and the addition of the entry point ENTER HORMAN, the flow chart was taken from Reference 2. The variable CTXTH = COS(TXTH) should be initialized outside this routine.

The horizontal resolution algorithm receives as input the X and Y position and velocity coordinates of the two aircraft requiring resolution commands. The estimated coordinates of the two conflicting aircraft may fall into three

mutually exclusive classes: (i) the aircraft are separating (i.e., the relative range is increasing with time); (ii) the aircraft are converging (i.e., the relative range is decreasing with time) and the track crossing angle is between TXTH (a system parameter) and 180 degrees; (iii) the aircraft are converging and the track crossing angle is between 0 and TXTH. The track crossing angle is the angle between the two velocity vectors, expressed as a positive angle between 0 and 180 degrees.

This third class above is further subdivided into three subclasses as follows. Let TTX1 and TTX2 be the times to track crossing point of aircraft 1 and aircraft 2, respectively. The track crossing point is the intersection of the two tracks defined by the two velocity vectors. Compute the two quantities, SA and SB.

$$SA=(TTX1-TIMEX)\bullet(TTX2-TIMETX)$$
$$SB=TTX1\bullet TTX2$$

TIMETX is a threshold with nominal value of 10 seconds. The three subclasses are iiia) $SA < 0$, iiib) $SA \geq 0$ and $SB < 0$, iiic) $SA \geq 0$ and $SB \geq 0$.

The condition that positive commands would be required when the aircraft are already separating is an abnormal one, but may arise due to the resolution logic for one nonresponding aircraft when the aircraft have come within the range for declaring an immediate conflict. If the aircraft are separating, the turn command to be issued to one aircraft is that one which turns that aircraft away from the second aircraft. In other words, if the second aircraft is in the left hemisphere as viewed by the pilot of the first aircraft, the first aircraft is given a "Turn Right" command. Both aircraft are given commands according to this same rule which is called Resolution Rule A.

If the aircraft are converging and the track crossing angle is between TXTH and 180 degrees the command to be issued to one aircraft is that

command which instantaneously increases the projected horizontal distance of closest approach. The projected horizontal distance of closest approach is the minimum horizontal separation between aircraft that would exist in the future if both aircraft were to maintain constant velocity vectors. Both aircraft are given commands according to this rule which is called Resolution Rule B.

A third rule called Resolution Rule C is also used. In this rule, the aircraft which has the larger time to track crossing point is issued the command which instantaneously increases the projected horizontal distance of closest approach. The other aircraft is issued the opposite command.

The rules used for the third class of geometries are:

Geometry	Rule
iiia (SA<0)	Rule C
iiib (SA≥0, SB<0)	Rule C
iiic (SA≥0, SB≥0)	Rule A

These rules are displayed graphically in Figure K-3-4.

The commands to be issued are determined mathematically in the following way. Compute

$$RX = X2 - X1$$
$$RY = Y2 - Y1$$
$$VRX = XD2 - XD1$$
$$VRY = YD2 - YD1$$

Let CTXA be the cosine of the track crossing angle. Then

$$CTXA = \frac{XD2 \cdot XD1 + YD2 \cdot YD1}{\sqrt{VSQ1 \cdot VSQ2}}$$

If CTXA < cos (TXTH), the track crossing angle is grater than TXTH.

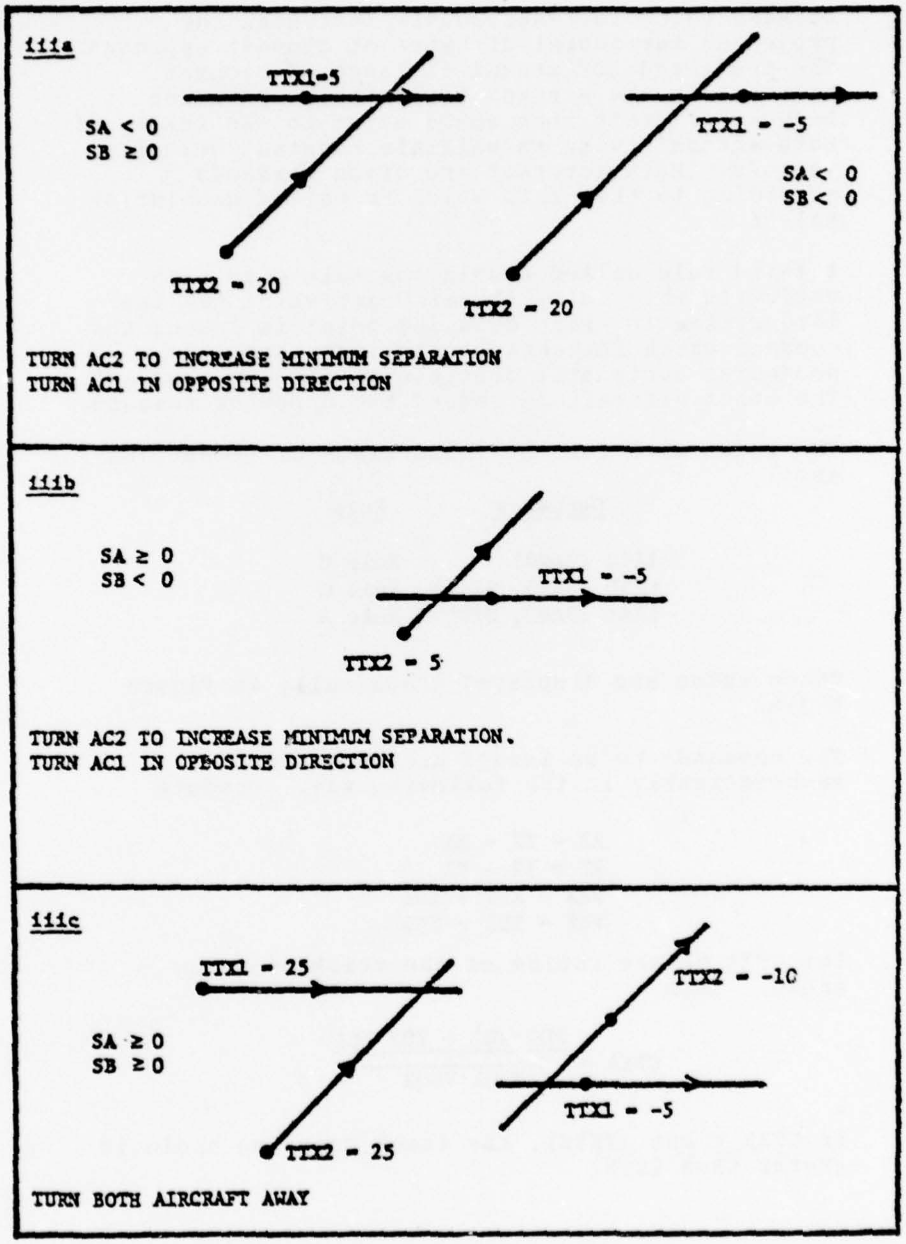


FIGURE K-3-4.

RESOLUTION RULES FOR LOW TRACK CROSSING ANGLES

Compute

$$DOT = RX \cdot VRX + RY \cdot VRY$$

The two aircraft are converging if DOT is negative and are separating if DOT is positive. The time to track crossing point can be computed, for aircraft 1 and 2, as:

$$TTX1 = \frac{RX \cdot YD2 - RY \cdot XD2}{XD1 \cdot YD2 - YD1 \cdot XD2}$$

$$TTX2 = \frac{RX \cdot YD1 - RY \cdot XD1}{XD1 \cdot YD2 - YD1 \cdot XD2}$$

Compute

$$C = RX \cdot YD1 - RY \cdot XD1$$

C has the same sign as the cross product between the velocity vector of Aircraft 1 and the relative position vector measured from Aircraft 1 to Aircraft 2. The sign of C indicates immediately whether Aircraft 2 is in the left hemisphere or the right hemisphere as viewed by Aircraft 1 and indicates immediately whether a right or left turn is required by Aircraft 1 to turn away from Aircraft 2. If $C > 0$, Aircraft 1 must turn left and if $C < 0$, Aircraft 1 must turn right.

For Aircraft 2, compute

$$C = RX \cdot YD2 - RY \cdot XD2.$$

If $C > 0$, Aircraft 2 must turn right to turn away from Aircraft 1 and if $C < 0$, Aircraft 2 must turn left. This specifies Rule A.

The calculation of Rule B is new discussed. Let the velocity magnitudes of the aircraft be V1 and V2 and let the angles of the velocity vectors

measured positive counterclockwise from the positive X-axis be $\alpha 1$ and $\alpha 2$. The direction in which each aircraft should turn to cause an immediate increase in the projected horizontal distance of closest approach will be determined by computing

$$\frac{\partial MD}{\partial \alpha 1} \text{ and } \frac{\partial MD}{\partial \alpha 2}$$

where MD represents the horizontal distance of closest approach.

$$VRX = V2 \cos\alpha 2 - V1 \cos\alpha 1$$

$$VRY = V2 \sin\alpha 2 - V1 \sin\alpha 1.$$

Let $S = \text{Sign}(RX \cdot VRY - RY \cdot VRX)$. Then by the familiar constant velocity formula

$$MD = \frac{S\cdot(RX\cdot VRY - RY\cdot VRX)}{\sqrt{VRX^2 + VRY^2}}$$

$$MD = \frac{S\cdot(RX\cdot V2\cdot\sin\alpha 2 - RX\cdot V1\cdot\sin\alpha 1 - RY\cdot V2\cdot\cos\alpha 2 + RY\cdot V1\cdot\cos\alpha 1)}{\sqrt{V1^2 + V2^2 - 2V1\cdot V2\cdot(\sin\alpha 1 \sin\alpha 2 + \cos\alpha 1 \cos\alpha 2)}}$$

The following derivatives are found.

$$\frac{\partial MD}{\partial \alpha 1} = -\frac{S\cdot(RX\cdot V1\cdot\cos\alpha 1 + RY\cdot V1\cdot\sin\alpha 1)}{\sqrt{VRX^2 + VRY^2}}$$

$$+ \frac{MD\ (V1\cdot\cos\alpha 1\cdot V2\cdot\sin\alpha 2 - V1\cdot\sin\alpha 1\cdot V2\cdot\cos\alpha 2)}{VRX^2 + VRY^2}$$

$$\frac{\partial MD}{\partial \alpha 2} = \frac{S\cdot(RX\cdot V2\cdot\cos\alpha 2 + RY\cdot V2\cdot\sin\alpha 2)}{\sqrt{VRX^2 + VRY^2}}$$

$$- \frac{MD(V1\cdot\cos\alpha 1\cdot V2\cdot\sin\alpha 2 - V1\cdot\sin\alpha 1\cdot V2 \cos\alpha 2)}{VRX^2 + VRY^2}$$

These partial derivatives can be computed in the following manner.

$$A = RX \cdot VRY - RY \cdot VRX$$

$$S = \mathrm{Sign}(A)$$

$$B2 = VRX^2 + VRY^2$$

$$B = \sqrt{B2}$$

$$MD = \frac{S \cdot A}{B}$$

$$D = \frac{MD \cdot (XD1 \cdot YD2 - YD1 \cdot XD2)}{B2}$$

$$\frac{\partial MD}{\partial \alpha 1} = -\frac{S \cdot (RX \cdot XD1 + RY \cdot YD1)}{B} + D$$

$$\frac{\partial MD}{\partial \alpha 2} = \frac{S \cdot (RX \cdot XD2 + RY \cdot YD2)}{B} - D$$

If $\frac{\partial MD}{\partial \alpha 1}$ is positive, Aircraft 1 is commanded to turn left and if negative to turn right, and similarly for Aircraft 2.

Rule C uses the same approach as derived above to determine the direction of turn for the aircraft further from the track crossing point.

K-3.7 Detection and Resolution Logic For Vertical Commands Only

The flow chart in Figure K-3-5 presents the logic used to select vertical only commands. This logic is used instead of the previous logic when the PAFLAG indicates that the quanlity of the X, Y data is not good enough for horizontal command selection. As the flow chart shows, the detection and resolution logic for this mode is essentially a simplification of the logic for the system described above. It is simpler primarily because

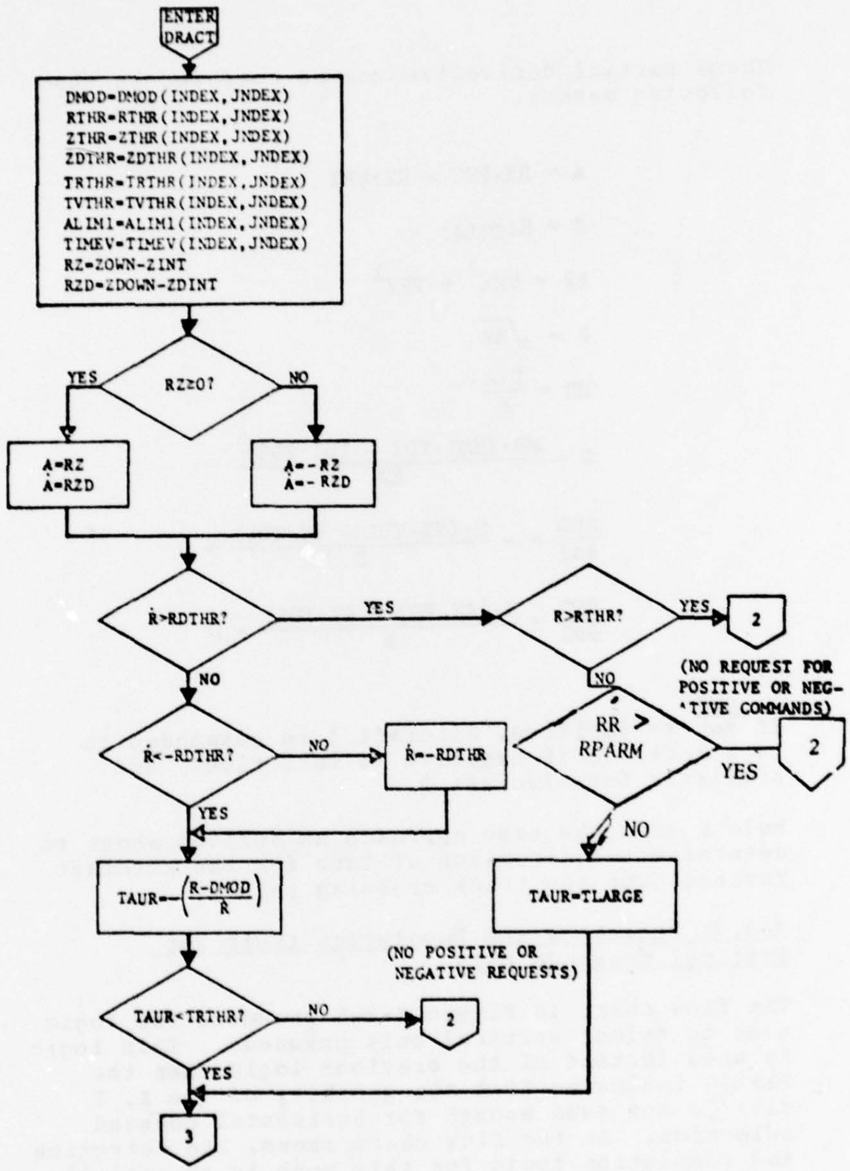


FIGURE K-3-5
DETECTION AND RESOLUTION FOR POSITIVE AND NEGATIVE COMMANDS- "Active Mode"
-DRACT-

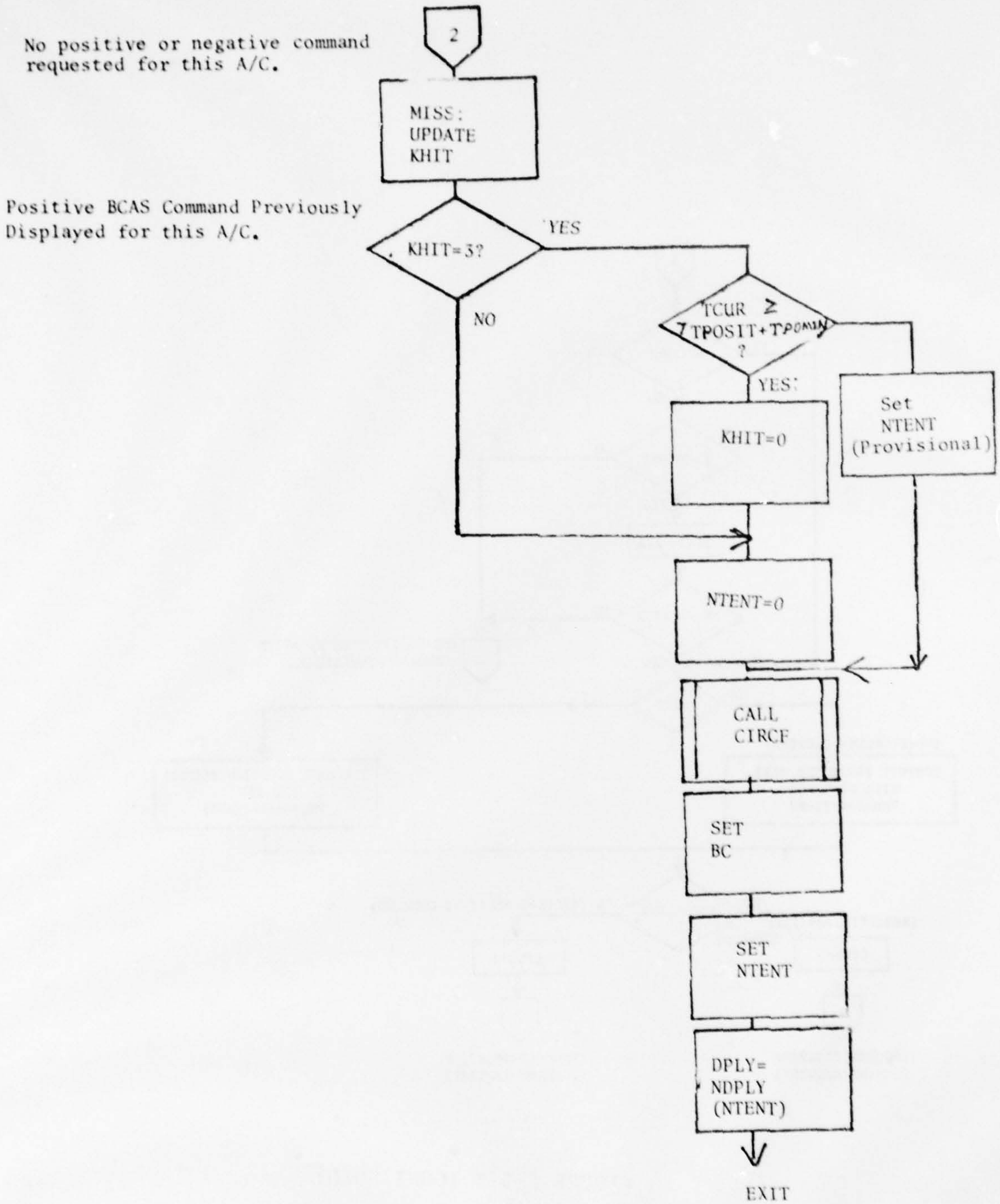


FIGURE K-3-5 (CONTINUED)
DETECTION AND RESOLUTION FOR POSITIVE AND NEGATIVE COMMANDS
_DRACT-

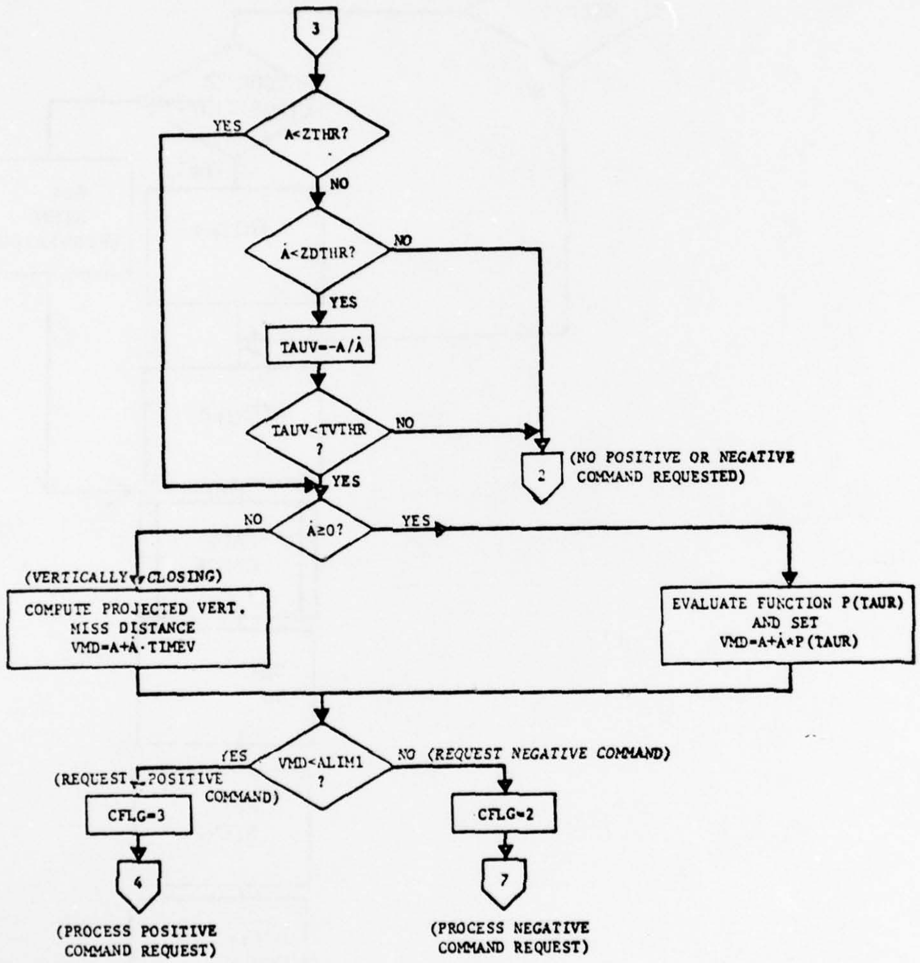


FIGURE K-3-5 (CONTINUED)

DETECTION AND RESOLUTION FOR POSITIVE AND NEGATIVE COMMANDS

-DRACT-

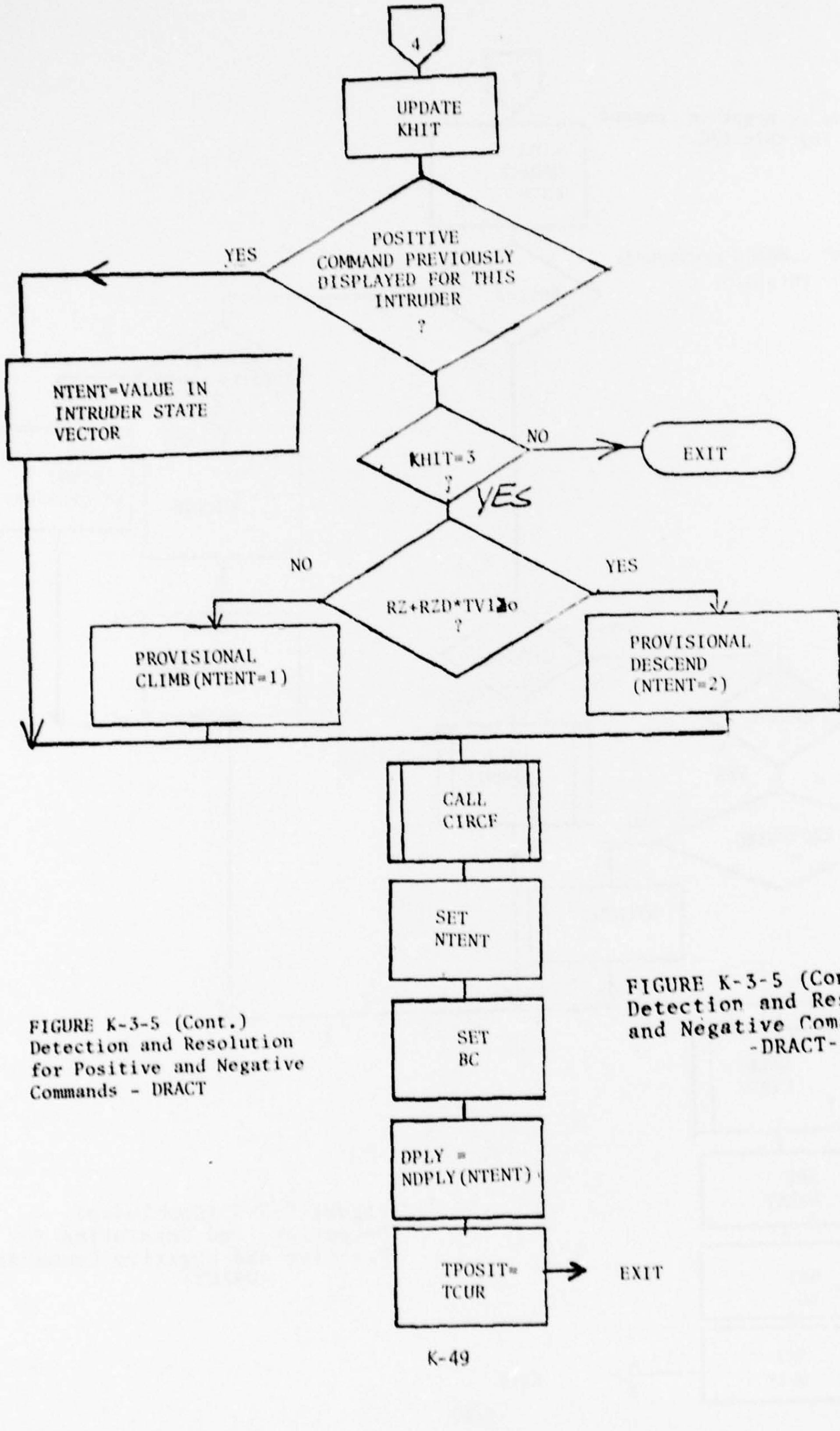


FIGURE K-3-5 (Cont.)
Detection and Resolution
for Positive and Negative
Commands - DRACT

FIGURE K-3-5 (Cont.)
Detection and Resolution
and Negative Comands
-DRACT-

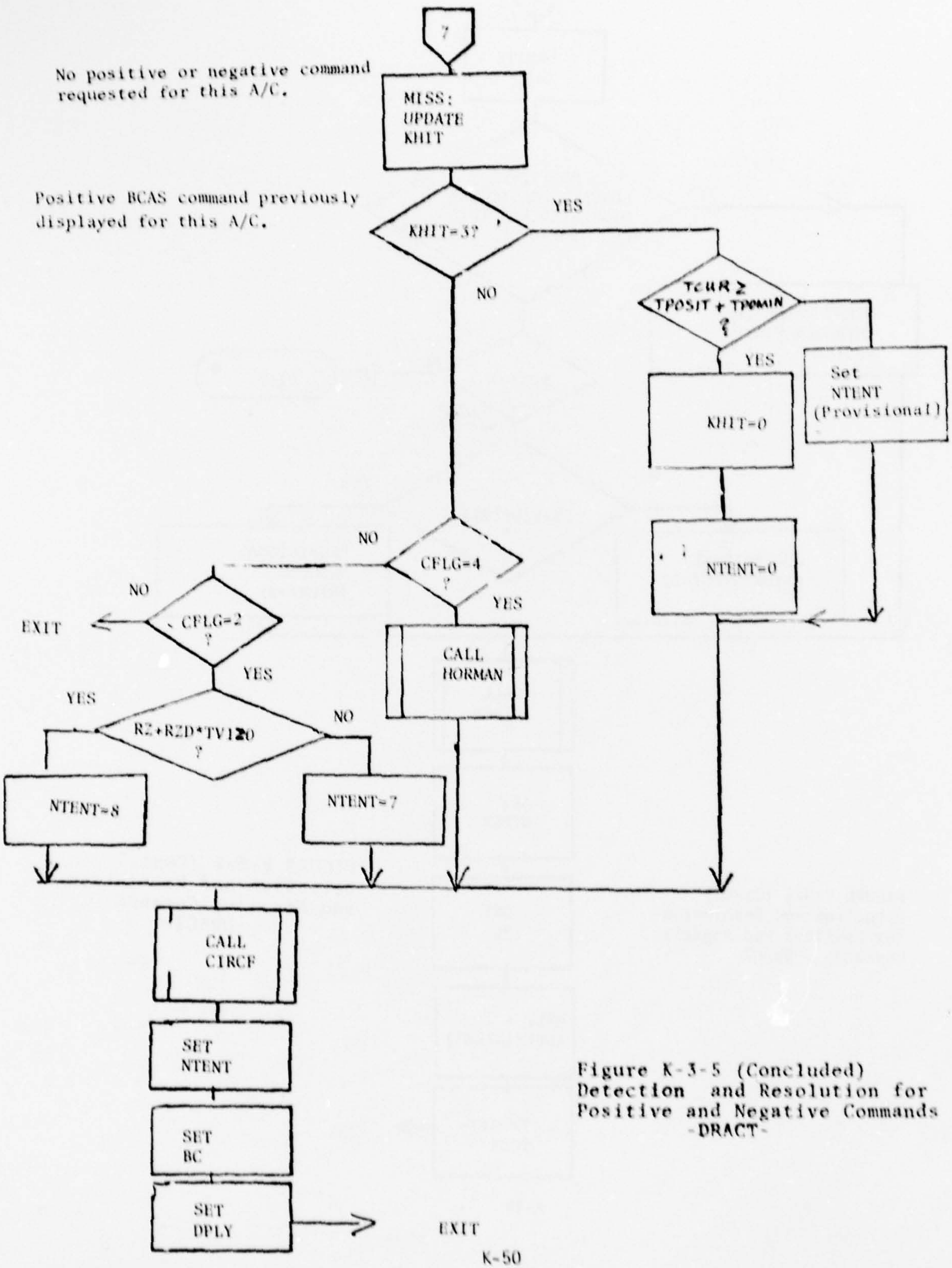


Figure K-3-5 (Concluded)
Detection and Resolution for Positive and Negative Commands
-DRACT-

only vertical collision avoidance maneuvers are considered. Thus, the conflict resolution logic is considerably simplified.

This section does not discuss the logic in detail since the discussion would only be an abbreviated repetition of the previous section. The flow chart of this logic should require no additional explanation for the reader familiar with the previous section's discussion. As shown, the parameter adaptation is identical except for the deletion of two parameters (viz., MDCMD and MDPOS), the substitution of ALIM1 for ALIM2 and the addition of the parameter TIMEV. The detection logic is the same except for the absence of two horizontal miss distance tests and the logic for requesting horizontal commands. Table K-3-4 shows the conditions under which both horizontal and vertical commands are selected.

TABLE K-3-4

HORIZONTAL AND VERTICAL COMMAND REFERENCE

	HIGH QUALITY DATA (PAFLG = 0)	LOWER QUALITY DATA (PAFLG = 1)
General Commands (Positive and Negative)	Vertical and Horizontal	Vertical Only
Vertical Miss Distance > ALIM	Negative Vertical	Negative Vertical
Vertical Miss Distance < ALIM and		Positive Vertical
1) Horizontal Miss Distance > MDPOS	Negative Horizontal	X
or		
2) Horizontal Miss Distance < MDPOS (See Figure K-3-1)	Positive Horizontal or Vertical	X

K-4. LIMIT VERTICAL RATE COMMAND LOGIC

Figure K-4-1 presents the flow chart of the logic which determines whether a vertical limit command should be displayed. This subroutine is only executed if no positive or negative commands have been requested for this intruder. Note that DPLY is always zero when entering this subroutine. If no limit commands are required, then DPLY is zero on exiting the subroutine. Otherwise, DPLY represents the limit command to be displayed as coded in Section K-8-3.

If the vertical separation A is very large (i.e., if A > LALT), limit commands are not needed, and the program exits. But if A is not as large as LALT, but is as large as L300 then the vertical rates of own aircraft and the intruder are checked. If both these are sufficiently small (e.g., < VR2) then the program exits, but if either rate is too large, the program computes the modified-tau variable TAU2 and compares it to the parameter TAU2L as a further test of whether a limit command is required. If not, the program exits with the display indicator DPLY = 0 to indicate no command.

However, if the test shows the need for a limit command, the program proceeds to compute the proper limit and its direction (i.e., up or down). If the vertical separation A does not exceed BAND1, and BAND2, the rate is limited to a maximum of 1000 feet/minute. Otherwise, A is between BAND2 and LALT, in which case the rate is limited to a maximum of 2000 feet/minute. The limit command is either a limit climb or a limit descent to the rate determined by the vertical separation A, the direction being determined by whether the intruder is above or below own aircraft. Before exiting, the program sets DPLY to the display code corresponding to the limit command just selected. No coordination is provided through the CIR Controller Coordination Function for vertical speed limit (VSL) commands. It is felt that those cannot be incompatible with either positive or negative commands. Simultaneous display of a VSL Command and a positive command would limit the required climb or descent to that specified in the VSL.

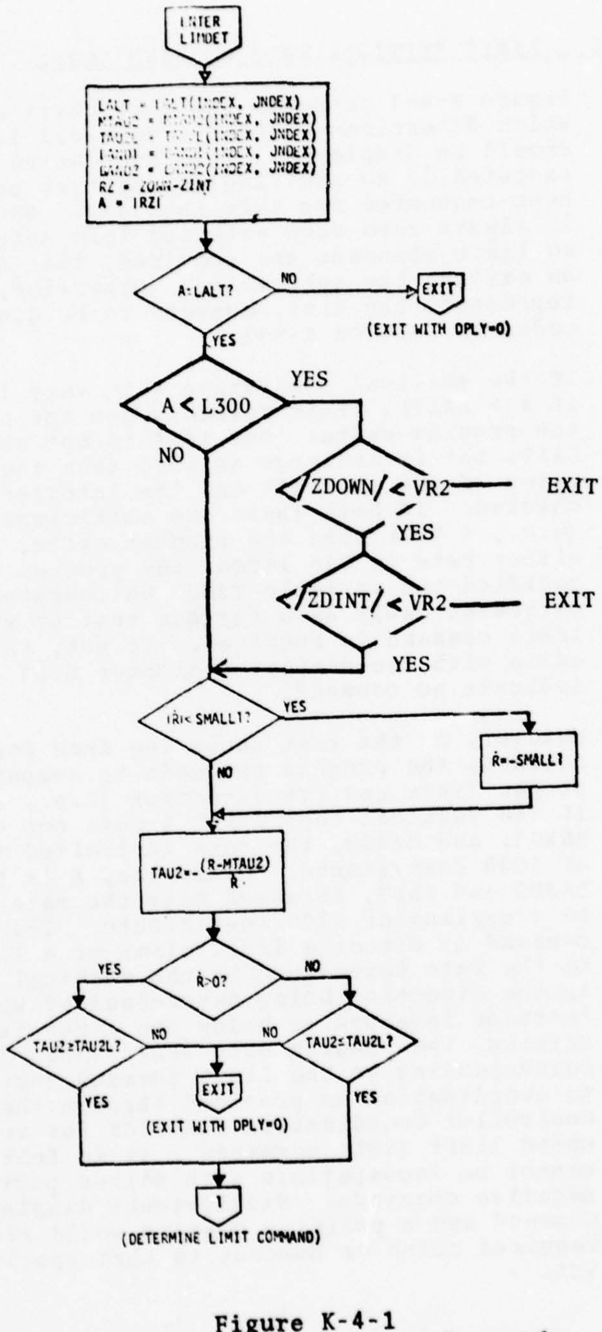


Figure K-4-1
Logic For Determining Limit Commands
-LIMDET-

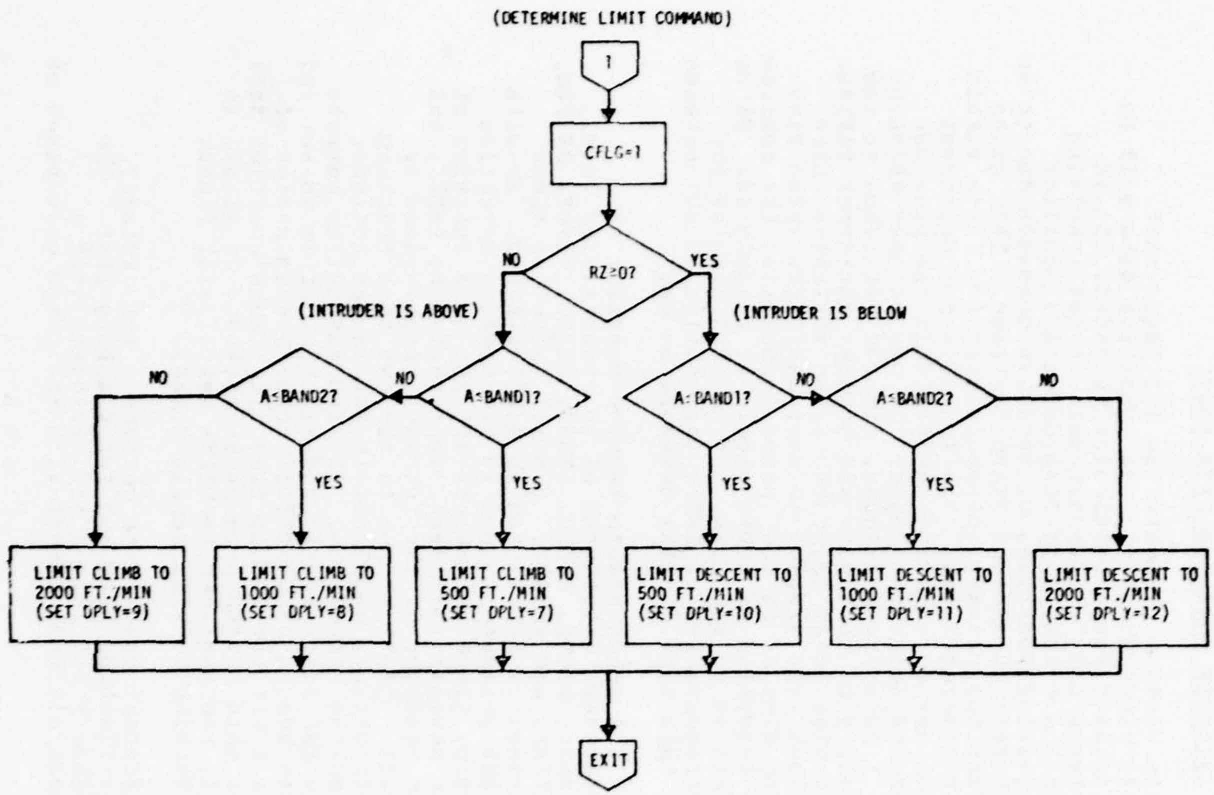


Figure K-4-1 (Cont.)
LOGIC FOR DETERMINING LIMIT COMMANDS (LIMDET)

K-5. INTRUDER POSITION DATA LOGIC

This section presents the IPD logic that determines whether or not position data will be displayed for a particular intruder. It is entered only if own aircraft is not receiving ATARS service or if BCAS detects a conflict requiring positive, or negative commands due to an aircraft outside of ATARS coverage. This gives ATARS the primary responsibility for IPD's within its coverage area. The logic is not dependent upon any calculation performed in the previous command detection logic. It can be used whenever X, Y data are available, without reference to the quality of that data and so does not check PAFLAG. The high level logic tests the variables CLIPD (clock type display in use) and PVIPD (plan view type display in use) prior to entering the routine to determine if IPD's should be calculated. Since there is no provision in the ACAS display for representation of IPD's the routine is not entered if this type display hardware is used.

The IPD calculations involve a number of parameters determined by the sensitivity level, namely, DMODP, RTHPO, RTHPF, TIPDO, TIPDF, RZIPDO, RZIPDF, and MDIPDF. Nominal values of these parameters are listed in Section K-8-2. As with other parameters used in the command detection logic, these parameters are set as a function of the sensitivity level, represented by INDEX, and the equipage of the intruder, represented by JNDEX. INDEX is set in the own data tracking subroutiine, and JNDEX is set in the intruder tracking subroutine. The IPD subroutine outputs the two flags IPDFIG and FLSHFL. If it is set and BCAS has assumed control through examination of its A bit the IPDFIG flag will cause position data for this intruder to be displayed. If FLSHFL is set, the intruder position symbol will flash; otherwise it will remain steady.

Different checks are performed for ordinary, non-flashing IPDs and for flashing IPDs. The ordinary IPD like ATARS, involves only a range/altitude cutoff with the range gate based on

aircraft speeds. The flashing IPD involves TAU and miss-distance tests.

Although an IPD is issued for a non-mode C intruder, the relative altitude for the non-mode C aircraft is unknown. Consequently an altitude filter has been provided that will display these IPD's only when own aircraft is below a certain altitude. This will reduce the number of non-mode C IPD's by eliminating those that are unlikely to be at co-altitude with a high flying aircraft. An appropriate mechanism should be provided for the display of this message.

K-6. DISPLAY LOGIC

The logic required to drive the aircraft display is divided into three pieces. The subroutine VECTOR forms part of the BCAS logic and writes display requests into the Display Request Queue for each aircraft processed by BCAS. The routine DISPLAY acts independently of the BCAS logic to read ATARS and BCAS display requests from the queue and write display vectors into the Display List. The Display Driver--also operating independently of the BCAS logic--reads the Display List an and lights the appropriate lights on the aircraft display. This section describes the logic making up the first two pieces of the display process. The third piece--the Display Driver is dependent on the actual display used and is considered to be largely hardwired; it is not described in this section.

K-6.1 Display Request

Logic has been provided in the routines VECTOR and DISPLAY to drive three types of displays, namely, the ACAS display, the IPD display, and the PVD display. The Airborne Collision Avoidance System (ACAS) display, described in reference 1 is capable of displaying CLIMB, DESCEND, DON'T CLIMB, DON'T DESCEND commands and limit vertical rate commands. It cannot display intruder position data. The Intermittent Positive Control (IPC) display, which is described in reference 2, can display positive or negative horizontal or vertical commands. In addition, it can display intruder position data expressed in own-heading oriented clock position and qualitative relative altitude information (intruder below, at same level or above). The third display that can be driven is an own-heading-oriented plan view display (PVD) in which one or more intruders can be presented at the correct relative bearing and range with additional character data presented in a data block attached to the intruder's position symbol.

It should be noted that the bearing displayed in

the IPC or PVD display is relative to own aircraft track, rather than own aircraft heading, thereby, disregarding wind effects.

A single output display vector is used to interface with all of the displays. This is shown in Table K-6-1. Several intruders may be represented by IPD's positive, negative or limit commands at one time.

The VECTOR subroutine shown in Figure K-6-1 forms a part of the BCAS logic. It is called to format the results each time BCAS processes an intruder aircraft. A request for action by the DISPLAY routine is written into the Display Request Queue. As shown in the figure VECTOR tests CLIPD to see if the clock type IPC display is used and if so, then VECTOR determines the appropriate relative altitude, RELALT, and clock position CLOCK. If the clock type display is not requested the VECTOR branches to the test for the PVD type display. Again a check is performed and if this display type is requested then the Range, Bearing, Altitude and other PVD fields are filled in the Display Request.

As a final act VECTOR writes the display request into the Display Request Queue.

K-6.2 Display List

The Display Processor Routine (DISPLY) reads both ATARS and BCAS messages out of the Display Request Queue and Updates the vectors in the Display List. It performs simple processing for BCAS commands to determine the paper settings of audible alarm and flash flags but ATARS commands and IPD's are self contained and do not require this processing. These are simply matched with vectors already in the Display list prior to being written into the list. If a vector with this aircraft ID already exists in the list it is overwritten by the new ATARS vector; if no such vector exists, the DISPLY routine adds the vector to the bottom of the Display List. A command is erased from the display by generation of a request for a null

TABLE K-6-1

ENTRIES IN DISPLAY LIST AND DISPLAY REQUEST

ITEM	INTERPRETATION	DISPLAY REQUEST	DISPLAY LIST
IDINT	Intruder ID	X	X
BC	System Responsibility Switch	X	X
DPLY	Command	X	X
CLKACK	Flag indication use of IPD Display	X	X
CLOCK	IPD clock position	X	X
RELALT	IPD relative altitude	X	X
PVACT	Plan View Display Flag	X	X
RANGE	Range to Intruder	X	X
BEAR	Bearing to Intruder	X	X
ALT	Intruder Altitude	X	X
EQ	Flag indicating Intruder has BCAS/ATARS/DABS	X	X
SCALE	PVD Scale	X	X
IPDFLG	Flag indicating Active IPD	X	X
FLASH	Flag indicating Flashing Message		X
AUD	Flag indicating Audible Alarm		X
FLASHFL	Flag indicating Flashing Message Requested	X	

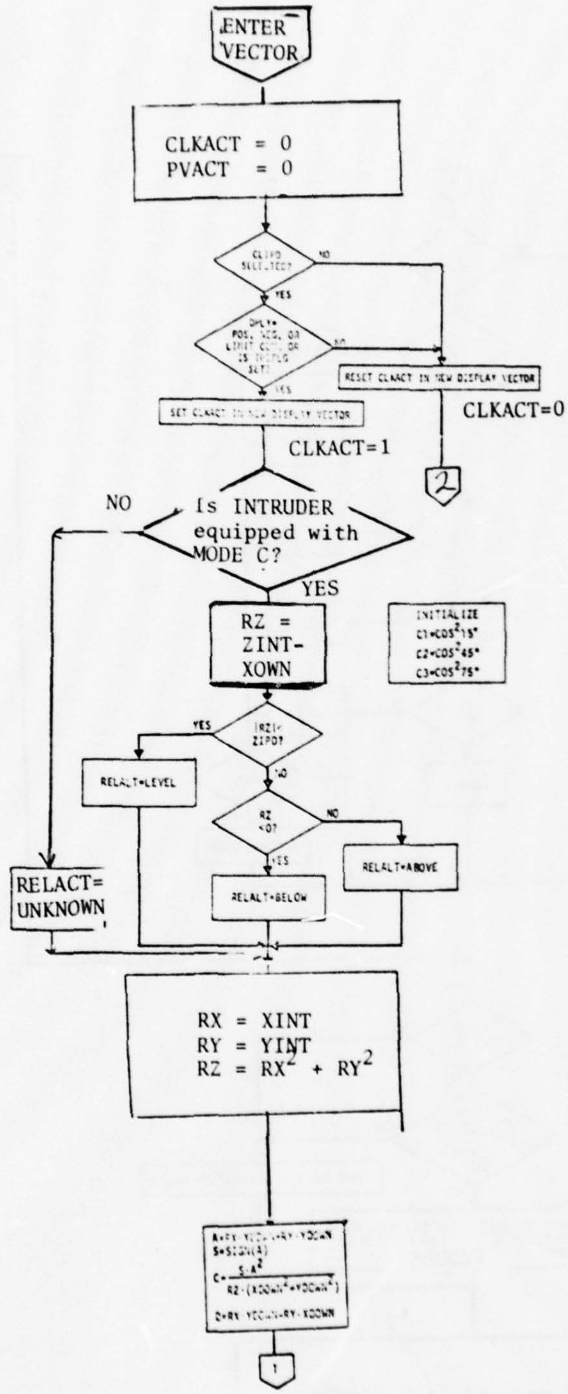


Figure K-6-1 BCAS Display Logic (Vector)

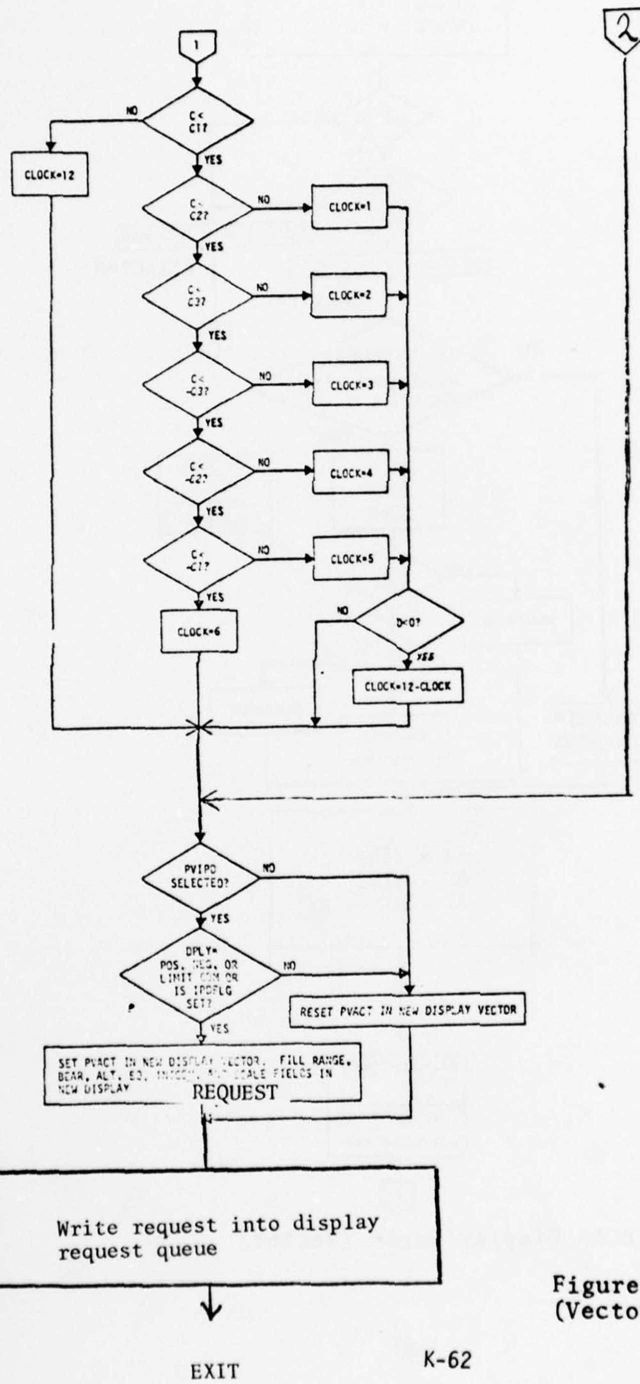


Figure K-6-1 BCAS Logic (Vector)

command. The first action taken by the DISPLY routine is a housekeeping task that deletes all null vectors from the Display List. Next DISPLY reads a request from the display request queue. If this is an ATARS originated command display, DISPLY simply searches the Display List for any other vector with the same intruder ID. If one is found, it is overwritten by the new vector; if no vector is found, DISPLY adds the new vector to the bottom of the list.

BCAS commands must be processed to determine the settings of the audible alarm and flash flags.

The first step in this is to interpret the command that will be displayed for this intruder. This is represented by the local variable CMDNEW. Next, the audible alarm flag in the display vector is determined using a look-up table. One index into the table is obtained from the previous display state for the intruder as determined by CMDSAV and FLASH, both of which are stored in the intruder state vector. The other index is obtained from current display information, specifically from CMDNEW and FLSHFL, which are computed by the IPD logic. The table is presented as Table K-6-2.

No audible alarm is given for limit commands. Audible alarm selection rules, consistent with ATARS are given below:

1. a transition from no command to a positive or negative command takes place,

2. a transition from a negative to a positive command take place,

3. a transition from one positive command to another positive command or from one negative command to another negative command takes place,

4. a transition from no flashing IPD to a flashing IPD takes place.

Note that only data applicable to a single

TABLE K-6-2

MATRIX GIVING SETTING OF AUDIBLE ALARM FLAG AS A FUNCTION OF OLD AND NEW DISPLAY CONDITIONS

	Old CMDSAV	Pos. Command	Neg. Command	No Pos. or Neg. Command	No Pos. or Neg. Command
New CMDNEW	Old FLASH / NEW FLSHFL	Any	Any	Off	On
Pos. Com.	Any	1	On	On	On
Neg. Com.	Any	Off	1	On	On
No Pos. or Neg. Com.	Off	Off	Off	Off	Off
No Pos. or Neg. Com.	On	Off	Off	On	Off

1. Audible alarm off if new command is same as old command, on if different.

intruder goes into this decision. The existence of commands or IPD's for other intruders does not prevent sounding the audible alarm for one of the above events for the given intruder.

Next, the FLASH flag in the display vector is set. This involves a simple transfer of the flag FLASHFL (Section K-6.1) from the Display Request to the Display List. If BCAS IPD's are selected, the intruder's position symbol flashes if positive, negative, or limit commands were desired, or if the IPD tests indicated the need for a flashing IPD.

The final two tests on CLKACT and PVACT simply transfer variables from the Display Request to the Display List.

DISPLY then returns to process the next request from the Display Request Queue. If all requests have been processed, the DISPLY routine should activate the Display Driver.

K-6.3 Display Driver

The function of the Display Driver is to read the Display List and to light the appropriate lights in the aircraft display. This is done by completely erasing the aircraft display and then lighting the lights corresponding to the vectors in the Display List. When all vectors have been processed the Display Dirver returns control to the DISPLY routine and a new display cycle begins. This complete cycle from the start of DISPLY through the Display Driver and back to the start of DISPLY should be repeated frequently to give prompt display of any commands. Suggested cycle time is 100 milliseconds. The display itself should appear to be continuously lighted.

K-7. TRACKING LOGIC

This section presents the tracking and airspace adaptation logic used by the BCAS collision avoidance logic. Tracking is performed separately for own aircraft and for intruder aircraft.

K-7.1 Tracking Own Aircraft (BTRACK)

Tracking of own aircraft takes place once per BCAS cycle, whether or not a potential conflict exists. Here the altitude and the horizontal and vertical rates are updated using simple fixed parameter tracking. Figure K-7-1 gives a flowchart of the tracking algirithm and Table K-7-1 lists the arguments in the call to the subroutine.

ALFAX, ALFAZ, BETAX and BETAZ are parameters and are listed in Section K-8-2. TDATA is a variable in own aircraft's state vector which gives the time for which the coordinates in own aircraft's state vector are represented. Other names are either local variables with obvious meaning in own aircraft's state vector.

This subroutine also contains logic to determine the set the of BCAS logic parameters. Since this set is a function of own aircraft's location, this can be done once per BCAS logic cycle in this routine. The result is contained in the variable INDEX, which is stored in own aircraft's state vector for use during the remainder of the BCAS cycle. The level of adaptation can be set by the ground ATC system through data link or it can be determined by the BCAS logic itself.

In the first case, ATC can select one of four possible levels by setting the input variable SLEVEL to 1, 2, 3 or 4. If ATC sets SLEVEL to 4, the collision avoidance logic is shut-off and the tracking program is not executed. In normal operation, however, only the first 3 levels are selected. The first level (SLEVEL = 1) is normally selected when own aircraft is at high altitude. The second level (SLEVEL = 2) is selected when own aircraft is at low altitude but

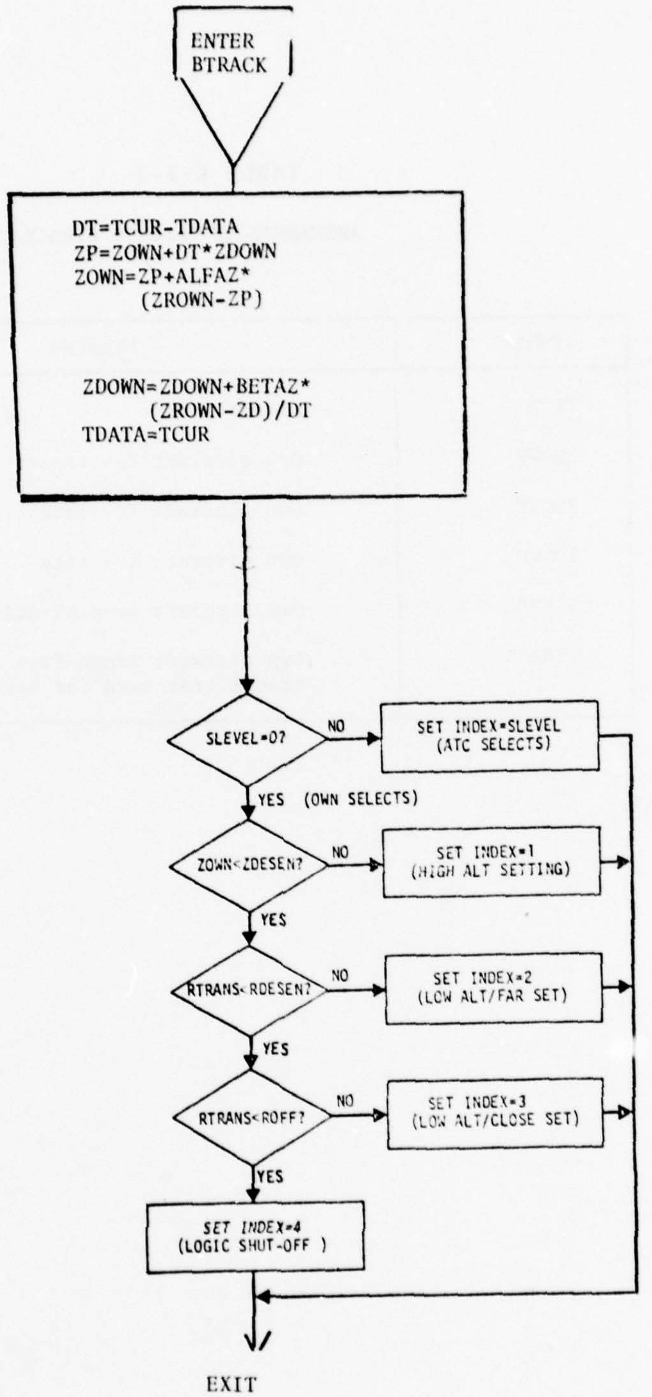


Figure K-7-1 Tracking Own Aircraft (Active and Passive Modes)

TABLE K-7-1

ARGUMENTS IN CALL TO BTRACK

SYMBOL	MEANING
TCUR	Curent time
ZROWN	Own aircraft Z - report
XDOWN	Own aircraft X - rate
YDOWN	Own aircraft Y - rate
SLEVEL	Own aircraft sensitization level
RTRANS	Own aircraft range from fixed ground transmitter used for desensitization

far out. Finally, the third level (SLEVEL = 3) is selected when own aircraft is at low altitude and close in. As indicated, the ground can select any one of these levels by setting SLEVEL to the proper positive integer.

However, as shown, if SLEVEL = 0, the program itself selects one of the first three levels or shuts off the collision avoidance logic. The logic bases its selection on own altitude, ZOWN, and distance, RTRANS, from a ground-based terminal area, choosing one of the following:

1. the high altitude setting if ZOWN > ZDESEN,

2. The low altitude but far out setting if ZOWN < ZDESEN and RTRANS > RDESEN,

3. the low altitude and close in setting if ZOWN < ZDESEN and ROFF < TRTANS < RDESEN.

4. the collision avoidance logic is shut-off if ZOWN < ZDESEN and RTRANS < ROFF.

So that the adaptation parameter selection is based on distance from a terminal area the value of the variable RTRANS received from the surveillance processor should reflect the range to a ground station that is to be used for selection purposes. This would not be the case with all radar beacon transponders (RBX). The intent is that crowded terminal areas require a different type of adaptation than relatively uncrowded en route or uncrowded terminal areas. Uplinks from the ground station should contain a bit indicating whether or not that station is to be used as a basis for parameter adaptation. The surveillance processor should decode this bit and use it to determine the value of RTRANS. RTRANS should be the range to the closest ground station that has the bit set. Some time-out feature should be provided to insure that RTRANS does not change values rapidly as codes are received from multiple stations causing RTRANS to oscillate back and forth.

If one of the first 3 levels is selected, either via ground control or program selection, each parameter is set to one of six possible values according to the desired sensitivity level and the intruder's equipage with BCAS. (Although an intruder may be equipped with DABS and a CAS display he is considered to be unequipped for parameter choices if he does not have BCAS.)

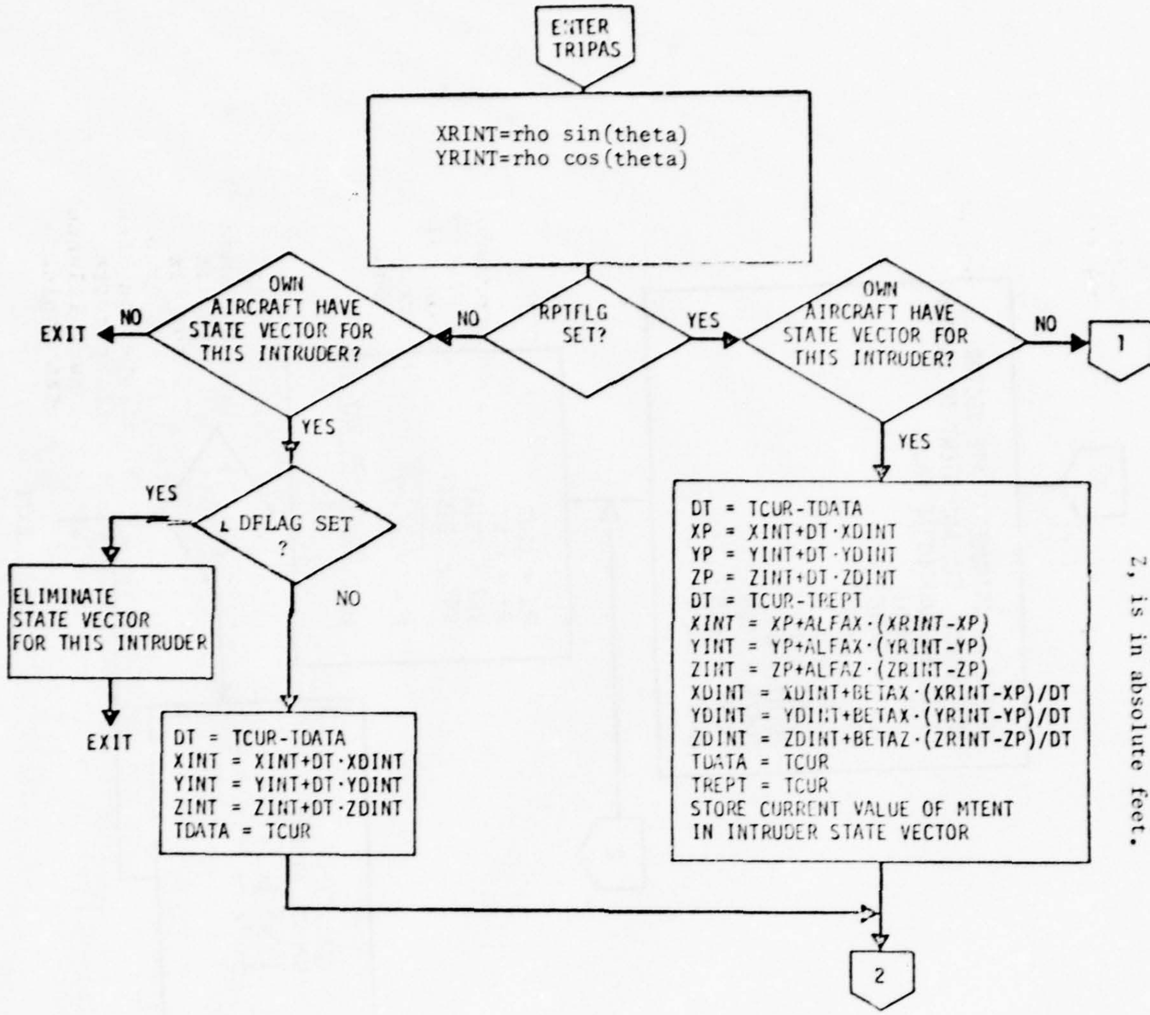
The following table summarizes the five integer values that can be assumed by the input variable SLEVEL:

SLEVEL VALUE	MEANING
0	Own aircraft selects level
1	ATC picks level (high altitude setting)
2	ATC picks level (low altitude/far setting
3	ATC picks level (low altitude/close setting)
4	ATC shuts-off collision avoidance logic

Provision should be made in the surveillance processor to reset the SLEVEL parameter to 0 whenever an update from ATC has not been received within a specified time period. This protects against an ATC failure or an aircraft leaving coverage with the SLEVEL remaining fixed by ATC.

K-7.2 Tracking Intruder Data (TRIPAS)

The flow chart for this subroutine is presented in Figure K-7-2 and the arguments in the subroutine call are given in Table K-7-2. This flow chart contains logic to create or eliminate a state vector for the given intruder. The intruder is dropped if the drop flag, DFLAG is set, and a state vector is started when an initial report is received. Reasonability tests will be applied to all raw reports by the surveillance processor before they are passed to the BCAS logic.



NOTE: X and Y coordinates are measured relative to own A/C. Altitude, Z, is in absolute feet.

FIGURE K-7-2
Tracking Intruder Aircraft

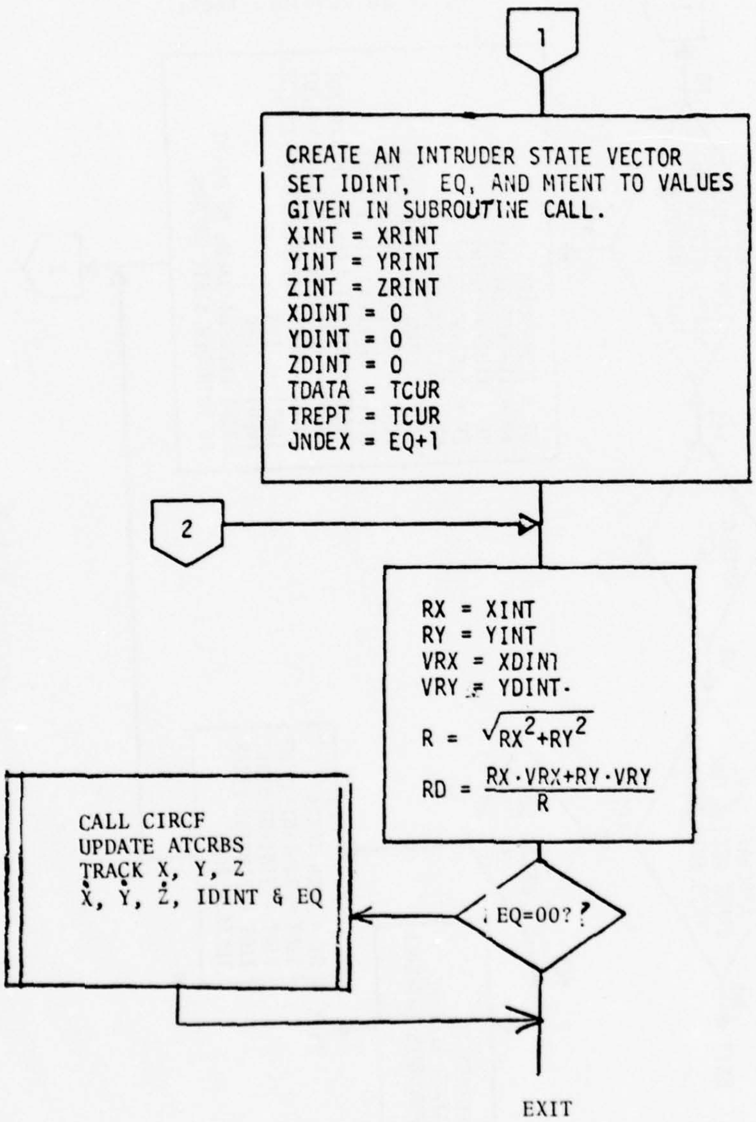


Figure K-7-2 (Concluded) Tracking Intruder Aircraft

TABLE K-7-2

ARGUMENTS IN CALL TO TRIPAS

SYMBOL	MEANING
TCUR	Current time
IDINT	ID of Intruder aircraft
RPTFLG	Flag indicating whether a surveillance hit has been received
rho theta ZRINT	Reports for Intruder (Relative range and bearing, absolute altitude)
EQ	2-bit flag indicating equippage of Intruder
DFLAG	Drop flag indicating that this track should be dropped

The flow chart includes logic to coast an intruder's track when a miss is reported by the surveillance processor; all position coordinates are linearly extrapolated and the velocity coordinates are left unchanged.

The surveillance processor (SP) acts as a front end to the BCAS logic by correlating raw target reports with tracks in its own track store. When a successful correlation is achieved the SP generates a BCAS target report which it writes into the surveillance report buffer. The flag RPTFLG is set to indicate that this is a reported hit. That is, that successful correlation has been achieved. If the SP does not receive a raw target report for some time or if it is unable to decode a report the SP will generate a reported miss for that aircraft and write this into the surveillance report buffer. The BCAS logic will then coast the intruder track based on this MISS. Thus, BCAS operates on only those aircraft for which it receives reports from the surveillance processor.

When a new intruder first appears, TRIPAS checks the Array of Intruder State Vectors to see if a track already exists for this intruder. Upon finding no track TRIPAS sets up a state vector for this intruder and writes it into the array. The track is started by using the reports directly for the position coordinates and by starting all velocity coordinates at zero. KHIT is also set to zero. A track is dropped when the BCAS logic receives a report with the drop flag, DFLAG, set. At this time the BCAS logic drops the track by deleting it from the Array of Intruder State Vectors. A null command should also be generated, (e.g., DPLY = 0) to remove any pre-existing commands from the CAS display. When a report on an ATCRBS threat appears the CIR Controller Coordination Function must be called to update the track data in the CIR row for this threat.

K-8 SUPPLEMENTARY INFORMATION

K-8.1 Testing Own Intent and Intruder's Intent for Compatibility

Table K-8-1 has been provided as a reference to be used to determine the compatibility of a provisional command with commands already displayed in own aircraft and with commands displayed in intruder aircraft as indicated by entries in own aircraft CIR. The lower half of the table gives compatibility (indicated by C) for commands generated within own aircraft or received from an intruder aircraft with commands already in existance on own aircraft display. The lower half of the table gives compatibility of commands generated within own aircraft with commands already existing in intruder aircraft display. Interpretation of the values of NTENT is given in Table K-3-3.

K-8.2 BCAS Collision Avoidance Logic Parameters

Table K-8-2 identifies system parameters of the logic described in this document and briefly describes their utilization. Nominal values are given to assist understanding the logics. Most of the parameters are used in both the passive and the active logics, but a few are special to only one logic. If a parameter is used in the passive logic, an X will appear opposite the parameter in column P. Similarly, if a parameter occurs in the active logic, an X will appear in column A. There are 6 nominal values for each parameter affecting desensitization: the first 3 values apply to the unequipped case, and the second 3 apply to the equipped case; they are stored in order of increasing desensitization within each grouping of 3.

K-8.3 Display Parameters

Table K-8-3 gives the values of the variable DPLY and the associated command that will be displayed in own aircraft.

TABLE K-8-1

TESTING OWN INTENT FOR COMPATIBILITY
WITH OWN DISPLAY AND WITH INTRUDERS INTENT

OWN INTENT (VALUE OF VARIABLE NTENT)

OWN COMMANDS IN DISPLAY	0	1	2	3	4	5	6	7	8	9	10	11	12
0	C	C	C	C	C	C	C	C	C	C	C	C	C
1	C	C	I	C	C	C	C	I	C	C	C	C	C
2	C	I	C	C	C	C	C	C	I	C	C	C	C
3	C	C	C	C	C	I	I	C	C	I	C	I	I
4	C	C	C	C	C	I	I	C	C	C	I	I	C
5	C	C	C	I	I	C	C	C	C	I	I	C	I
6	C	C	C	I	I	C	C	C	C	I	I	I	I
7	C	I	C	C	C	C	C	C	C	C	C	C	C
8	C	C	I	C	C	C	C	C	C	C	C	C	C
9	C	C	C	I	C	I	I	C	C	C	C	C	C
10	C	C	C	C	I	I	I	C	C	C	C	C	C
11	C	C	C	I	I	C	I	C	C	C	C	C	C
12	C	C	C	I	C	I	I	C	C	C	C	C	C

COMMAND SENT

OWN INTENT (VALUE OF VARIABLE NTENT)

INTRUDERS INTENT (VALUES IN INTRUDERS DISPLAY)	0	1	2	3	4	5	6	7	8	9	10	11	12
0	C	C	C	C	C	C	C	C	C	C	C	C	C
1	C	I	C	C	C	C	C	C	I	C	C	C	C
2	C	C	I	C	C	C	C	I	C	C	C	C	C
3	C	C	C	I	I	I	C	C	C	C	C	I	I
4	C	C	C	I	C	I	I	C	C	C	C	I	I
5	C	C	C	I	I	C	I	C	C	I	I	C	C
6	C	C	C	C	I	I	I	C	C	I	I	C	C
7	C	C	I	C	C	C	C	C	C	C	C	C	C
8	C	I	C	C	C	C	C	C	C	C	C	C	C
9	C	C	C	I	C	I	C	C	C	C	C	C	C
10	C	C	C	I	C	I	C	C	C	C	C	C	C
11	C	C	C	I	I	C	C	C	C	C	C	C	C
12	C	C	C	C	C	I	I	C	C	C	C	C	C

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
ACCEPT	Altitude separation within which own aircraft accepts intruder's slection of vertical command when own selection is incompatible.	X	X	400 ft.
ALFAR	Tracking constant for range		X	0.4
ALFAX	Tracking constant for X and Y position	X		0.4
ALFAZ	Tracking constant for Z position	X	X	0.4
ALIM1	Vertical miss distance within which positive rather than negative vertical commands are requested.		X	700 ft. 400 400 700 400 400
ALIM2	Vertical miss distance in excess of which negative vertical commands are requested rather than horizontal commands or positive vertical commands	X		700 ft. 400 400 700 400 400
BAND1	Altitude separation within which vertical rate is limited to a maximum of 500 ft./minute	X	X	1300 ft. 1000 800 1300 1000 800

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
BAND2	Altitude separation within which vertical rate is limited to a maximum of 1000 ft./min.	X	X	1800 ft. 1500 1000 1800 1500 1000
BETAR	Tracking constant for range rate		X	0.15 ft.
BETAX	Tracking constant for X and Y velocity	X		0.15 ft.
BETAZ	Tracking constant for Z velocity	X	X	0.15 ft.
DMOD	Modified-tau distance used for positive and negative commands	X	X	1.8 nmi 0.75 0.3 1.8 0.75 0.3
DMODP	Modified-tau distance used for IPD detection	X		1.8 nmi 0.75 0.50 1.8 0.75 0.50

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
LALT	Altitude separation outside which vertical rate limit commands are not given	X	X	3300 ft. 1500 1000 3300 1500 1000
L300	Altitude difference used to test desirability of issuing VSL messages	X	X	300 ft.
MDCMD	Square of horizontal miss distance threshold beyond which no positive or negative maneuvers are requested by threat detection logic	X		9.0 nmi^2 4.0 1.0 9.0 4.0 1.0
MDIPDF	Square of horizontal miss distance threshold used in flashing IPD test	X		1.0 nmi^2 0.25 0.25 1.0 0.25 0.25
MDPOS	Square of horizontal miss distance threshold used by threat detector to choose between positive and negative command requests	X		1.0 nmi^2 0.25 0.16 1.0 0.25 0.16

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
MTAU2	Modified-tau distance used to determine whether vertical limit commands should be given	X	X	1.8 nmi 0.75 0.3 1.8 0.75 0.3
PFUN	Weights used to estimate the predicted vertical miss distance	X	X	4.0 sec. 7.2 9.8 11.8 13.5
RDESEN	Range threshold used to desensitize logic at low altitude	X	X	15 nmi
RDTHR	Range-rate threshold use to choose between Tau test and immediate range test	X	X	10 ft./sec.
ROFF	Range threshold used by program to shut off collision avoidance logic	X	X	2 nmi
RPARM	Protection volume parameter	X	X	.00277778
RTHPF	Immediate range threshold for flashing IPD tests	X		1.0 nmi 0.5 0.3 0.5 0.3 0.3

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
RTHPO	Immediate range threshold for ordinary IPD tests	X		3.0 nmi 2.0 1.0 3.0 2.0 1.0
RTHR	Immediate range threshold used in threat detection for immediate range test	X	X	2.0 nmi 0.75 0.3 1.0 0.5 0.3
RZIPDF	Immediate altitude threshold for flashing IPD tests	X		700 ft. 400 400 700 400 400
RZIPDO	Immediate altitude threshold for ordinary IPD tests	X		2000 ft. 1500 1000 2000 1500 1000

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
SMALL1	Small value used to avoid dividing by zero when computing TAU2.	X	X	10 kts.
TAU2L	Threshold against which TAU2 is compared to determine whether limit commands should be given	X	X	40 sec. 40 40 40 40 40
TDROP	Time without reported data to drop an intruder	X	X	10 sec.
TIMETX	In horizontal resolution, the time to track crossing point threshold	X		10 sec.
TIMEV	Look-ahead time used to compute the projected vertical miss distance VMD to determine whether to request a positive command or a negative command		X	25 sec. 20 20 25 20 20
TIPDF	Tau threshold for flashing IPD tests	X		35 sec. 30 30 35 30 30

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
TIPDO	Tau threshold for ordinary IPD tests	X		60 sec. 60 60 60 60 60
TLARGE	Very large positive number	X	X	10^5 sec.
TPOMIN	Minimum time positive command can be displayed	X	X	5 sec.
TRTHR	Value against which modified-tau (TAUR) is being compared	X	X	30 sec. 30 25 25 25 20
TVPCMD	Look-ahead time used to compute the projected vertical miss distance VMD	X	X	25 20 20 25 20 20

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Continued)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUE
TVTHR	Value against which vertical tau (TAUV) is being compared	X	X	30 sec. 30 25 25 25 20
TV1	Look-ahead time used to choose climb or descend command	X	X	8 sec.
TXTH	In horizontal resolution algorithm, the track crossing angle at which the resolution strategy changes	X		90°
VR2	Altitude rate used to test desirability of issuing VSL messages	X	X	2 ft./sec.
WAITM	Maximum reply wait time	X	X	.4.0 sec.
ZDESEN	Altitude threshold below which logic is desensitized	X	X	10,000 ft.
ZDTHR	Altitude rate threshold used by the threat detection (Note: ZDTHR = -ZTHR/TVTHR)	X	X	-30 ft./sec. -30 -36 -36 -36 -45
ZIPD	Altitude threshold for co-altitude IPD	X		500 ft.

TABLE K-8-2

BCAS COLLISION AVOIDANCE LOGIC PARAMETERS
(Concluded)

SYMBOL	UTILIZATION	P	A	NOMINAL VALUES
ZTHR	Immediate altitude threshold used by detection logic	X	X	900 ft. 900 900 900 900 900
ZTOP	Altitude ceiling below which IPDs for non mode C A/C will be issued	X		14,000 ft.

TABLE K-8-3

DISPLAY INDICATOR CODES

DPLY	COMMAND DISPLAYED
0	no command selected
1	don't climb
2	don't descend
3	level off
4	(not used)
5	climb
6	descend
7	don't climb faster than 500 ft./min.
8	don't climb faster than 1000 ft./min.
9	don't climb faster than 2000 ft./min.
10	don't descend faster than 500 ft./min.
11	don't descend faster than 1000 ft./min.
12	don't descend faster than 2000 ft./min.
13	don't turn right
14	don't turn left
15	turn left
16	turn right

Table K-8-4 translates values of the variable NTENT, indicating own and intuder intent into display codes DPLY. The first column gives translation for positive commands while the second column gives translation for negative commands. Notice that several values of NTENT may be mapped into a particular value of DPLY by the function NDPLY.

K-8.4 The Function P(T) Used to Compute the Vertical Miss Distance When A > 0 and Index = 3

The function P(T) is evaluated at time T = TAUR in order to compute the projected vertical miss distance VMD in TAUR seconds from the current time. The distance VMD is set to A + A*P(TAUR) and then compared to the threshold ALIM to determine whether a positive vertical maneuver should be given.

P(0) = 0 since the current vertical separation is A. Furthermore, since A > 0, P(T) is an increasing function of time. However, to be on the safe side in projecting the vertical separation and deciding whether to request a positive command, P(T) is assumed to be less than the linear projection, i.e., P(T) < T; and to reflect the increasing uncertainty of A as T increases, the rate of growth of P(T) is assumed to decrease in time. There are many functions that have the foregoing desired shape, for example, the are under the curve e in the interval 0 < T < TRTHR where the constant a is chosen to reflect the increasing uncertainty of A.

For the present purpose, P(T) is approximated by a piece-wise linear function whose linear segments have endpoints at T = 0, 5, 10, 15, 20, and 25 seconds. The values of P at these endpoints are stored in the array PFUN (see Table K-8-2). Approximating P in this manner permits very easy programming. Figure K-8-1 shows the piece-wise linear approximation. Note that P(T) = P(TRTHR) for T > TRTHR.

TABLE K-8-4

FUNCTION NDPLY GIVES DISPLAY VALUE

NTENT	DPLY	NEGATIVE COMPLEMENT DPLY
0	0	0
1	5	7
2	6	8
3	15	13
4	15	13
5	16	14
6	16	14
7	1	
8	2	
9	13	
10	13	
11	14	
12	14	

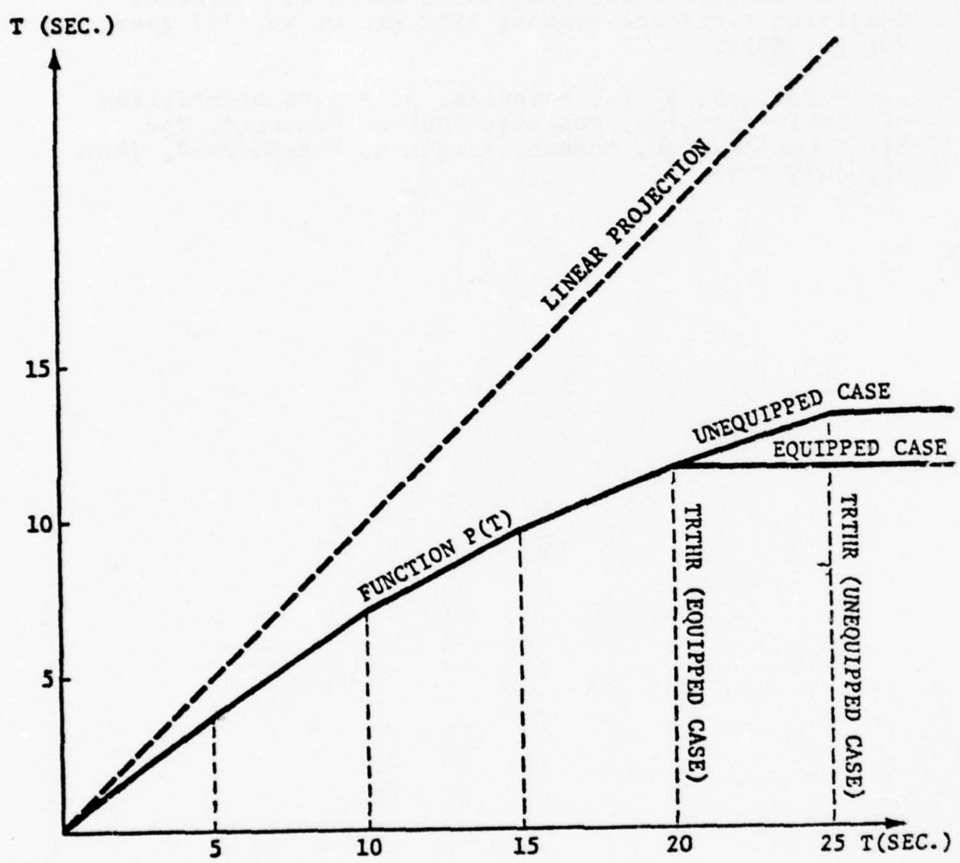


FIGURE K-8-1

FUNCTION P(T) FOR BOTH EQUIPPED AND UNEQUIPPED CASES

REFERENCES

1. Air Transport Association of America, "Airborne Collision Avoidance System, ANTC Report No. 117 (Rev. 10) May 1971.

2. McFarland, A. L., Horowitz, B. M., "A Description of the Intermittent Positive Control Concept", The MITRE Corporation, McLean, Virginia, FAA-EM-74-1, (Rev. 1), July 1975.

APPENDIX L

DEVELOPMENT OF AN INTERFACE BETWEEN ATARS AND BCAS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

L-1. INTRODUCTION

Due to the fact that Automatic Traffic Advisory and Resolution Service (ATARS, formerly IPC) (Reference 1 and 2) and Beacon-based Collision Avoidance System (BCAS) (Reference 3 and 4), may simultaneously be in use onboard an aircraft, it is necessary to establish an interface which will enable the two systems to operate simultaneously in an effective manner. This document describes an algorithm concept for the interface, presents computer decision logic, and identifies the minimum airborne communications capabilities required to support it.

There are several generic problems in creating an effective mechanism for delegating system responsibilities. Three key problems include pop-up intruders (those which enter DABS surveillance from beneath the coverage floor and cause an immediate collision threat), resolution of multiaircraft (> 2) encounters, and transient boundary effects.

To resolve these problems, BCAS-originated collision avoidance commands are to be inhibited wherever separation assurance by ATARS is available. This leads to a definition of separate but contiguous ATARS and BCAS service zones, depicted in Figure L-1-1. Note that BCAS would still be permitted to acquire and track targets, perform detection, etc., in all airspace. Only its commands would be prevented from being displayed to the pilot, within the ATARS service zone.

It is required that an aircraft equipped with BCAS shall also be equipped with a modified DABS (Discrete Address Beacon System) (Reference 5) transponder. An aircraft equipped with a DABS transponder does not necessarily have a CAS (Collision Avoidance System) display attached to it.

Compatible ATARS and BCAS multiaircraft collision avoidance logic is assumed to exist. A

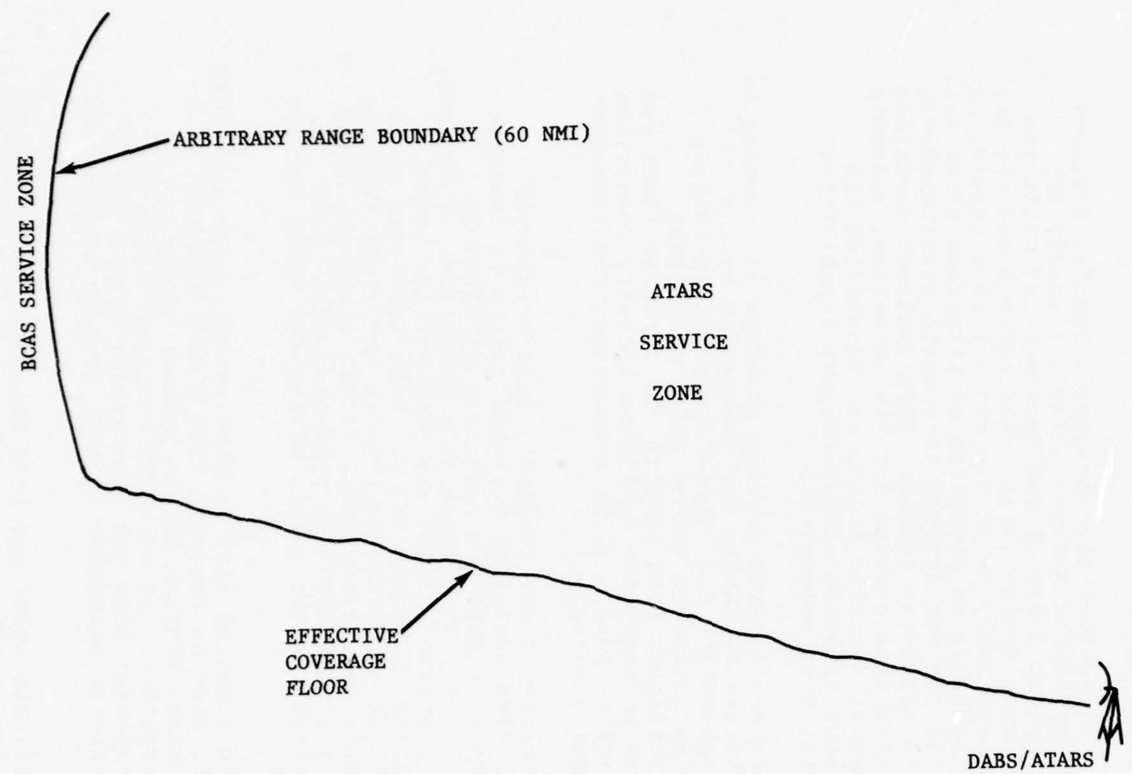


FIGURE L-1-1
SERVICE ZONE DEFINITION

distinction related to this is that a mechanism which designates which system is responsible for separating a conflicting pair of aircraft is different from collision avoidance logic that determines which commands to send to them. This appendix is exclusively devoted to the former.

In the following chapter, the interface is described in terms of actions that occur when ATARS and/or BCAS detects a conflict between aircraft at or near the boundary between the ATARS and BCAS service zones. It will be shown how rapid and unambiguous designation of system responsibility can be achieved using a first-come-first-served dynamic interlock, whereby an action performed by one system locks out subsequent action by the other system. It shall also be demonstrated how multiaircraft encounters can be coordinated, by successive pairwise applications of the dynamic interlock. The information contained in ground to air, air to air and air to ground coordination messages will be described, including a feature whereby BCAS to BCAS tie breaking data can be integral with the air to air handshaking used in the interface.

Next, computer decision logic and messages needed to realize the interface are presented and discussed in detail. A special register which is the focus of all system responsibility transactions is described, as well as a function which oversees and controls its activity. Finally, the ramifications of adopting this interface upon current designs are identified.

Before proceeding to a discussion of the interface's behavioral characteristics, one further point needs to be made. Although every attempt was made to verify correctness of the logic, time was not available to stress it with every conceivable case. An analysis of the number of different possible combinations of equipage, ground coverage at the beginning of the conflict, coverage transitions during the conflict, sequence of coordination messages being sent, signal fades, etc., just for a three aircraft encounter, showed

that this number is very large. Since exhaustive testing was not performed, the material presented in this document should be considered a first design and not a final algorithm specification.

L-2. BEHAVIORAL CHARACTERISTICS OF THE INTERFACE

In this section, the basic mechanisms of the interface's operation shall be described, both in general and using specific examples. The nature of a special register, central to the functioning of the interface, will also be discussed. Presentation of detailed decision logic, which utilizes that register and initiates and responds to special coordination messages, is deferred to the following section.

L-2.1 Interface Design Goals

The ATARS-BCAS interface is required to achieve a certain set of design goals. Foremost among them is that it provides what shall be referred to as continuity and compatibility. By continuity it is meant that once an aircraft receives a command, the system originating it does not change abruptly; the same system manages that conflicting pair of aircraft over the entire duration of the collision threat. (Note that this property does not preclude the system from altering a command it has given, in the face of non-response of an aircraft.) Two levels of compatibility have been identified. On one level, compatibility means that a particular aircraft does not receive a contradictory set of commands (e.g., CLIMB and DIVE). On the other level, compatibility means that all conflicting aircraft (in a two- or multi-aircraft encounter) receive a mutually consistent command set, so that the hazard is not worsened by incorrect commands. Related to compatibility is the property that only one system be permitted to issue a command to an aircraft due to a particular threat.

Another important design goal is that ATARS should be the responsible system wherever separation assurance by both ATARS and BCAS is achievable. This goal would be fairly easy to achieve, by simply having ATARS inhibit BCAS commands in all aircraft visible to ATARS. However, another property, which can conflict with inhibiting BCAS, is that protection be provided against pop-up

intruders. This situation occurs, for example, when an aircraft beneath the floor of DABS coverage is in danger of colliding with an aircraft within DABS coverage but close to the coverage floor. Combining the dominance of ATARS with protecting against pop-up intruders implies that an aircraft within DABS coverage may receive an ATARS command due to a threat aircraft visible to ATARS, at the same time as receiving a BCAS command due to a second threat below DABS coverage. It is the task of the interface to sort things out and assure that the subject aircraft does not receive incompatible commands from the two systems.

A further property the interface is required to possess is that it be able to coordinate correctly in multiaircraft (> 2) conflicts. It is the ambiguity as to which of several threats a system is attempting to issue commands for, that necessitates the inclusion of threat ID's in all air to air and air to ground replies. It was found in an interface design alternatives study that in going from no ATARS-BCAS coordination capability to coordination of two-aircraft conflicts, the bulk of the additional complexity lay in computer logic, while only a few dedicated bits were required in existing message formats. In going from two-aircraft to N-aircraft coordination capability, the major penalty is that much larger amounts of data need to be transferred between the computers, the additional logical complexity being less significant.

Two additional required properties that are related to each other is that the interface be resilient to transient communications losses (ground fades, antenna shielding, etc.), and that minimum additional time delay in the pilot receiving the commands be introduced due to coordination. For example, coordination must not be delayed for several scans of the DABS sensor if an aircraft's bottom-mounted antenna is shielded from view during a turn. Another example is that successive downlink-uplink cycles on separate scans would not be permitted for coordination.

Even if extended lead times were provided for such a scheme, cases would occur in a large ensemble of trials where the actual lead time available before collision is insufficient.

One last requirement is that a unique Proximity Warning Indicator (PWI) be associated with each target aircraft.

L-2.2 CAS Indicator Register

It is convenient at this point to introduce the special register which is the central repository of responsibility information. It is called the CAS (Collision Avoidance System) Indicator Register, or CIR. See Figure L-2-1 for a depiction of the CIR structure. A CIR is to be located in every aircraft containing an operating CAS display, whether it be supplementing only a DABS transponder or both a DABS transponder and a BCAS unit. Of course, an aircraft equipped only with an ATCRBS transponder or no transponder, will not have a CIR. The CIR need not be a special piece of hardware; depending on the avionics technology used, it may be a dedicated segment of random access memory, it may be defined by a microprocessor when needed, etc. The meanings of the CIR bits and bit fields are now addressed.

When the A bit is set, this indicates that the aircraft containing that CIR is currently being provided separation assurance by ATARS. On every surveillance interrogation (Reference 5), ATARS must command the A bit to be set if the aircraft qualifies for ATARS detection and resolution by virtue of being within the ATARS service zone (see Figure L-1-1).

The site ID field (four bits) is to be used in ATARS multisite coordination, and does not participate in ATARS-BCAS interface actions.

The CIR has only one A bit and site ID field. All other bits and bit fields are repeated in distinct rows, one for each simultaneous threat (see Figure L-2-1). If there are no threats, the CIR may

consist of only an A bit and site ID field, or of an A bit and site ID field followed by one row of null bits and bit fields. As new threats appear, the computer may define additional rows in the CIR, and release them as the corresponding threats disappear. In this way, the interface will be able to coordinate for an arbitrary number of simultaneous threats. The following discussion refers to a single threat (refer to Figure L-2-1).

If the B bit is set, the aircraft has committed itself to BCAS for providing separation from the threat; if the C bit is set, the responsible system is ATARS. The B and C bit *cannot both* be set at the same time. They may both be null, however, if the aircraft is currently involved in negotiating responsibility for separation from the indicated threat. The D field contains the command being displayed to the pilot. If the C bit is set (own aircraft may be equipped with BCAS or only DABS and a CAS display), the D field contains the ATARS-originated command being displayed to the pilot. If the B bit is set and own aircraft is equipped only with DABS and a display and not with BCAS, the D field contains a BCAS command complement, which is not displayed to the pilot. For example, in a DABS vs. BCAS encounter where BCAS is responsible, suppose BCAS has commanded its pilot to descend. Then the contents of the D field in the DABS aircraft would be CLIMB, and this would not be displayed to its pilot. The contents of the D fields are used as constraints in command selection when secondary, tertiary, etc., conflicts materialize.

The ID field of the CIR contains information related to the identity of the threat aircraft. If the threat is DABS equipped, the ID field contains the threat's twenty-four bit DABS ID (Reference 5). If the threat is ATCRBS equipped, the ID field contains all zeros, which is understood to mean that the next CIR row contains the threat's track relative to own. This relative track (relative range, relative bearing, relative altitude, and their rates) is used to identify the ATCRBS-equipped threat to other computers.

Associated with the CIR row for such a threat is also a local ID, by which the ATARS-BCAS interface and the BCAS on the same aircraft identify it when communicating with each other.

Finally, the E bit is set when air to air handshaking, a process to be described later in this section, is in progress.

L-2.3 Example Conflict Scenario

Rather than describing each part of the coordination process in general, several specific conflict scenarios (see Figure L-2-2) shall be traced through. In Figure L-2-2, an X marks the position of an aircraft when the hazard materializes. The ATARS and BCAS service zones are configured as in Figure L-1-1.

Consider scenario A. Both aircraft are well within the ATARS service zone, and consequently, their A bits are both set. When BCAS on aircraft 1 detects a hazard, it locks its CIR, assigns a row to the ID of aircraft 2, sets the E bit in that row, and fills the D field of that row with a provisional BCAS command. Next, it immediately transmits a special interrogation, referred to as a coordination interrogation, addressed to aircraft 2. The coordination interrogation contains the ID of aircraft 1; an indication that aircraft 1's A bit is set, and the complement of the provisional BCAS command stored in its D field. When aircraft 2 receives the coordination interrogation, it locks its CIR (if it is not busy), and then transmits a coordination reply which contains everything in its CIR except its site ID field and E bits. If its was busy when the coordination interrogation was received, aircraft 2 replies, in effect, "CIR busy; try again", whereupon aircraft 1 would retransmit the same coordination interrogation, and so on. After replying the DABS aircraft checks its CIR to see if its A bit is currently set. It is, and the BCAS command complement is rejected. When BCAS on aircraft 1 receives the coordination reply, it recognizes that aircraft 2 is being given ATARS

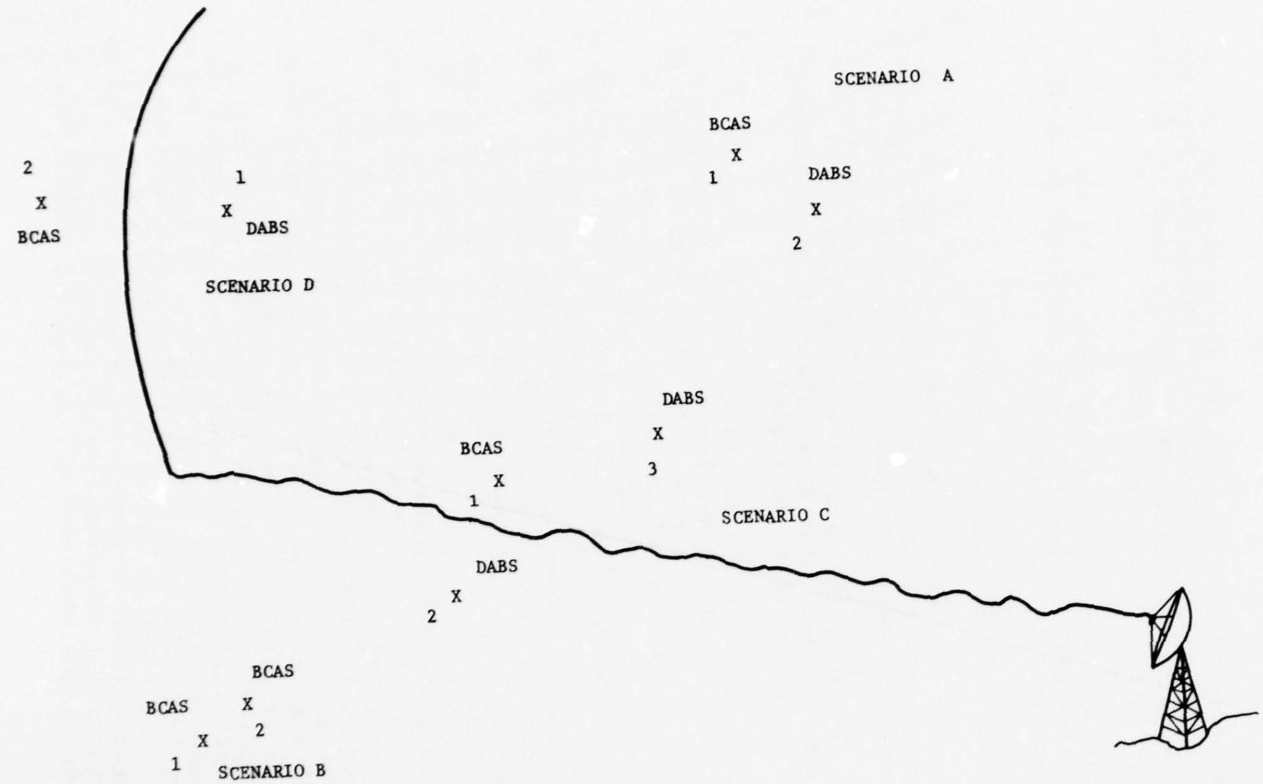


FIGURE L-2-2
EXAMPLE CONFLICTS

service, since aircraft 2's A bit is set. Upon checking own CIR, BCAS finds that aircraft 1 is itself also being given ATARS service (since own A bit is set); BCAS then unlocks its CIR and surrenders the conflict to ATARS. In this way, BCAS is made to self-suppress when both own and threat are within ATARS protection.

Next consider Scenario B. Suppose BCAS on aircraft 1 is first to detect hazard. As in Scenario A, BCAS locks own CIR, sets up a row for aircraft 2, and sends a coordination interrogation to aircraft 2. Aircraft 2 locks its CIR, reads out its contents into the coordination reply, and examines the information sent in the coordination interrogation. That information identifies the sender as aircraft 1, and indicates that aircraft 1's A bit is not set. Upon checking own CIR, BCAS on aircraft 2 finds no row assigned to the ID of aircraft 1, so that it establishes one, and sets the B bit committing to BCAS (because there are not two A bits set). When BCAS on aircraft 1 receives the coordination reply, it sees that aircraft 2's CIR contained no row assigned to aircraft 1, and that aircraft 1's A bit was not set. It then sets own B bit for aircraft 2, displays the BCAS command to its pilot, and unlocks the CIR. Thus when both aircraft are outside the ATARS service zone, BCAS resolves the conflict.

Scenario C involves the coverage floor boundary of the ATARS service zone, as well as a third aircraft, and so the full capability of the interface can be illustrated. According to the placement of the aircraft, it can be deduced that the A bits of aircraft 1 and 3 are set, while that of aircraft 2 is not set. Suppose the first conflict to materialize is aircraft 1 vs. aircraft 2. The air to air handshaking informs BCAS on aircraft 1 that aircraft 2 is outside ATARS service, so BCAS sets own B bit corresponding to aircraft 2, and displays the associated command (stored in the D field of that same row) to its pilot. The next time ATARS interrogates aircraft 1, the entire contents of its CIR (except for the

E bit) are downlinked. Upon receiving this information, ATARS sets up a conflict table for the 1-2 conflict, including the ID of aircraft 2 and the BCAS command being displayed to the pilot of aircraft 1. The conflict table also specifically indicates that BCAS is responsible for resolving that conflict.

Next, aircraft 3 comes into conflict with aircraft 1. Air to air handshaking informs BCAS on aircraft 1 that both own and threat are within ATARS protection, so it surrenders to ATARS. When ATARS detects the 1-3 conflict, it selects a command set which is compatible with aircraft 1's BCAS command, which it finds from referencing the existing conflict table. ATARS then uplinks the command to aircraft 1, along with the ID of aircraft 3. Upon receiving the ATARS message, aircraft 1 locks own CIR, compares the message with own CIR, and finds that no row has yet had its bit set for aircraft 3. It also finds that the ATARS command does not conflict with any other pre-existing command. If a command incompatibility had been detected, the ATARS command would be rejected by aircraft 1. ATARS would then be forced to wait one more scan, during which it would reselect a command for aircraft 1 which is compatible with the BCAS command and with the ATARS command accepted by aircraft 3. (This delay can be avoided by using extended ATARS lead times.) In the case of rejection, ATARS may also re-select the entire command set for the 1-3 conflict. In the normal sequence of events where the ATARS command is not rejected, aircraft 1 then sets the C bit in the CIR row associated with aircraft 3, stores the ATARS command in that row's D field, displays the ATARS command to its pilot, and unlocks own CIR. ATARS, of course, uplinks a command to aircraft 3, which sets up the appropriate CIR fields, etc. Thus, it can be seen that compatibility of commands is assured by matching coordination message information with the contents of the CIR, and that provision has been made to protect against the pop-up intruder.

Suppose the first conflict to materialize had been

aircraft 1 vs. aircraft 3. Then the first row in aircraft 1's CIR would have the C bit set, and an ATARS command in the D field. When aircraft 2 comes into conflict with aircraft 1, BCAS on aircraft 1 is able to select an evasive maneuver compatible with the ATARS command already being displayed (if such selection is possible based on the BCAS operating mode). One should bear in mind that the CIR controller is all the while granting access to own BCAS logic, air to air coordination message processing, and ATARS command message processing, one at a time. If the CIR is busy when the aircraft receives an interrogation from the ground, it does not reply. The airborne computer and electronic equipment must be fast enough so that an aircraft will be able to emit a reply during the DABS main beam dwell time. That is, during the approximately twenty interrogation-reply cycle times available during one sweep of the DABS surveillance beam, the CIR shall be available and a reply emitted with high probability.

In Scenario D, ATARS violates its own arbitrary range boundary in order to assume responsibility for separating this pair. This implies that ATARS must be cognizant of aircraft beyond the range boundary (since DABS surveillance certainly will not end at that boundary), but does not take action for conflicts wholly outside its service zone. In Scenario D, ATARS, aware that BCAS is operating on aircraft 2 (this information is routinely downlinked) commands this aircraft's A bit to be set at a special extended lead time. When BCAS on aircraft 2 detects a hazard and performs air to air handshaking with aircraft 1, it discovers that both aircraft's A bits are set. BCAS then surrenders to ATARS. When the hazard worsens and the command lead times are reached, ATARS uplinks commands to both aircraft. If a hazard fails to materialize (i.e., actual ATARS detection thresholds are not crossed), ATARS resets the A bit in any aircraft currently outside its service zone.

Some additional features of the interface can be

illustrated using Figure L-2-3. In scenario E a conflict between two BCAS equipped aircraft materializes when both aircraft are beneath the DABS coverage floor. Air to air handshaking establishes BCAS as the responsible system. Then, as indicated by the arrows, both aircraft become visible to ATARS while the BCAS command is still posted to the pilot of aircraft 1. On each interrogation from the ground, both aircraft would be downlinking the contents of their CIR's. ATARS sets up a conflict table for this pair, indicating BCAS as the responsible system, and does not uplink commands even though the conflict is wholly within the ATARS service zone. From this type of action, one is prompted to refer to the boundary between the ATARS and BCAS service zones as a "soft" boundary. It can also be noted that if the boundary involved in this scenario were the range boundary, the same events would occur.

The reverse of this conflict is depicted in scenario F. Here, a conflict between a BCAS and a DABS-equipped aircraft materializes within the ATARS service zone, so ATARS is the responsible system. Even though BCAS is inhibited from displaying commands, it is still free to periodically issue coordination interrogations to the threat aircraft, as long as it perceives a hazard. As the aircraft drop out of DABS coverage in the middle of resolving the conflict, the (nominally) once per second air to air coordination messages are converted into requests to update the timeout for the command existing on the display. Therefore the ATARS-originated commands remain posted as long as BCAS believes a collision threat exists. It is seen from this example that the boundary between the ATARS and BCAS service zones is soft in both directions. If the boundary in this scenario were the range boundary instead of the coverage floor, ATARS would simply violate it and continue uplinking commands even though both aircraft are outside the nominal ATARS service zone.

Finally, in scenario G, a BCAS-equipped aircraft comes into conflict with an ATCRBS-equipped

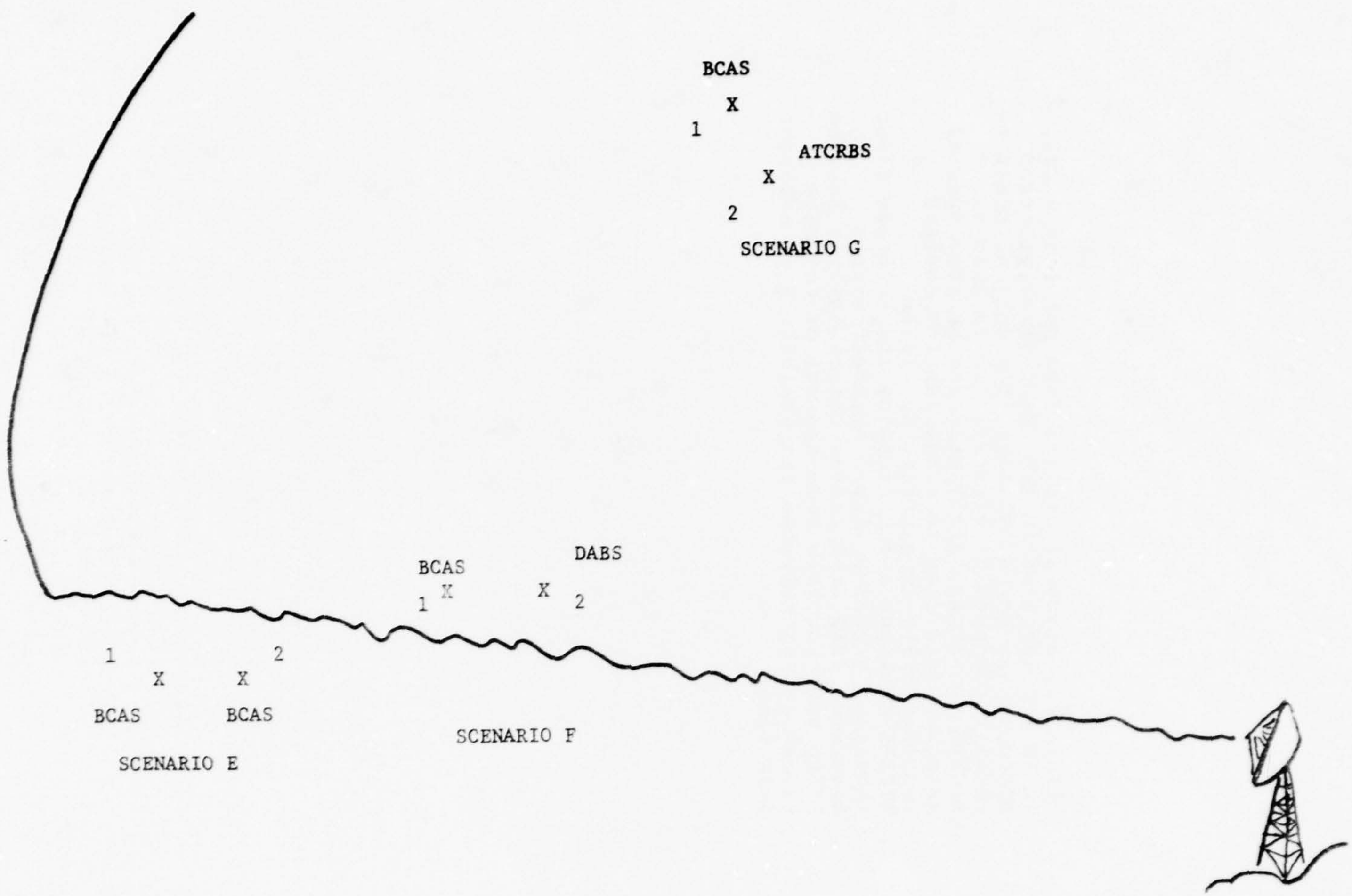


FIGURE L-2-3
EXAMPLE CONFLICTS

aircraft. Since aircraft 2 does not have a CIR, it is not involved in the negotiation process. Since it has no CAS display, the only aircraft to receive commands is aircraft 1. In BCAS vs. ATCRBS conflicts, ATARS will use another special extended lead time to establish its command responsibility in aircraft 1. If an ATCRBS-equipped aircraft below the coverage floor threatens a BCAS-equipped aircraft within coverage, BCAS will assume responsibility because ATARS will not have seen the out of coverage threat and established responsibility at a longer lead time.

L-3. LOGICAL DESIGN OF THE INTERFACE

In this section, software structures and detailed decision logic for the ATARS-BCAS interface are presented and discussed. First, the high-level relationship between the BCAS collision avoidance logic and the ATARS-BCAS coordination function is described, including messages sent between the two activities. Then, the logical design of the CIR controller is presented, followed by decision logic flow charts for the actual coordination between ATARS and BCAS. Logic is included both for DABS transponders with CAS display but without BCAS, and for DABS-BCAS units. The section is concluded with a discussion of additional necessary logical features.

L-3.1 Communications Between BCAS Collision Avoidance Logic and ATARS-BCAS Interface

The functions which track targets, detect conflicts, select (provisional) commands for evading them, and drive the cockpit display are described in Appendix K. For the sake of logical clarity, this activity has been kept distinct from the ATARS-BCAS interface. This subsection addresses the (intra-computer) messages sent between these two activities.

Communication between the BCAS collision avoidance algorithms and the ATARS-BCAS interface is always initiated by the BCAS algorithms. Three types of messages can be sent from them to the interface, and each has its own type of response. The first message type is sent when BCAS has detected a conflict, selected provisional commands for resolving it, and desires coordination for finalizing them. Then the message sent to the interface consists of the threat ID, together with the provisional command set (e.g., OWN TURN RIGHT, THREAT TURN LEFT), which is referred to as the variable NTENT in Appendix K. It is the task of the interface to test the OWN part of this provisional command set for compatibility with other commands own aircraft might already be following, and to coordinate own's desire to

resolve the conflict with other computers involved. Specifically, the interface determines whether or not own has already committed to ATARS for resolving the indicated conflict, and if not, performs air-to-air handshaking with the threat aircraft to establish compatibility with the threat's intentions (provided that the threat is not ATCRBS-equipped). Any level of incompatibility (between pre-existing own commands, prior commitment by own or threat to ATARS, or pre-existing threat's intent) is resolved by the ATARS-BCAS collision avoidance interface, and the results are returned to the BCAS algorithms. If air-to-air handshaking determines that the A bits of both own and threat are set, this fact is communicated to own BCAS. When BCAS desires to drop the command for an old threat (and only if the B bit is set for that threat), this message is sent to the interface one last time, with a null command set (NTENT = 0). The interface logic will recognize this as a command deletion, and will wipe the corresponding row(s) from the CIR.

The second type of message sent by the BCAS algorithms is a request for own A bit (this information is used in the ATARS-BCAS PWI filter), and the corresponding reply is own A bit. The third message type is a track update for an ATCRBS threat, separation from which has already been committed to BCAS. Since this type of threat is identified to other computers by its position and velocity relative to own (it is part of the CIR), it is necessary to update this identification whenever own tracker estimates are updated. To facilitate correlation of the updated track with the old one already in the CIR, a local threat ID is included in this message. Since no use is made by BCAS of the knowledge that the track in the CIR has been updated, no reply is sent.

The intra-computer message set is summarized in Table L-3-1.

TABLE L-3-1

INTRA-COMPUTER MESSAGE SET FOR COMMUNICATION BETWEEN BCAS ALGORITHMS AND THE ATARS-BCAS INTERFACE

MESSAGE SENT FROM BCAS ALGORITHMS	REPLY SENT FROM ATARS-BCAS INTERFACE
1. THREAT ID + PROVISIONAL COMMAND SET*	1. THREAT ID + { OWN 'B' AND 'C' BITS, OR BOTH 'A' BITS SET, OR COMMITTED COMMAND IF OWN 'B' BIT SET
2. OWN 'A' BIT REQUEST	2. OWN 'A' BIT
3. ATCRBS THREAT TRACK UPDATE: LOCAL ID + $(X,Y,Z,\dot{X},\dot{Y},\dot{Z})$ RELATIVE	3. NO REPLY

* COMMAND SET IS NULL IF BCAS IS DROPPING AN OLD COMMAND.

L-3.2 CIR Controller

The software mechanism which oversees the use of the CIR is referred to as the *CIR Controller*. The purpose of the CIR Controller is to permit only one function at a time (branch of logic, reply to air to air coordination interrogation, etc.) to be serviced by the CIR. In this way, it prevents scrambling of coordination actions due to time-interleaving of events. A function desiring access to the CIR causes a lock command to be sent to the CIR Controller, along with the ID of the threat with which that function is currently concerned. If the CIR is not busy, the CIR Controller grants access to the CIR to that requesting function, and simultaneously locks out other functions from gaining access. When the function is finished using the CIR, an unlock command is sent to the CIR Controller, which then frees the CIR for access by other functions. If a function sends a lock command to the CIR Controller while the CIR is busy, the CIR Controller denies access to the CIR by replying "CIR busy", and a loop keeps sending lock commands until it gains access. A state transition matrix for the CIR Controller is presented in Figure L-3-1.

One further level of state granularity was omitted from Figure L-3-1 for the sake of clarity. The state of being locked in order to service BCAS air-to-air coordination may be thought of as having two substates. One of these occurs when own BCAS has initiated air-to-air coordination, the other when own aircraft is responding to a coordination interrogation it has received from a threat BCAS. The meaning of this shall be explained in the following subsections.

If the function desiring access to the CIR is servicing an interrogation received from another system (i.e., ATARS or a remote BCAS), the following actions occur. A partial decoding of the interrogation determines the nature of the sender. If the sender is BCAS and if the CIR is in the UNLOCKED state, its contents are read out

CURRENT STATE

FUNCTION TO BE SERVICED (REQUEST)			LOCKED UNDER THREAT ID1, TO SERVICE OWN BCAS LOGIC	LOCKED UNDER THREAT ID1, TO SERVICE BCAS AIR-TO-AIR COORDINATION INTERROGATION	LOCKED UNDER THREAT ID1, TO SERVICE UPLINKED ATARS COMMAND	LOCKED UNDER THREAT ID2, TO SERVICE OWN BCAS LOGIC	LOCKED UNDER THREAT ID2, TO SERVICE BCAS AIR-TO-AIR COORDINATION INTERROGATION	LOCKED UNDER THREAT ID2, TO SERVICE UPLINKED ATARS COMMAND	UNLOCKED
THREAT ID1	OWN BCAS LOGIC	LOCK	--	LOCKED, ID1, COORD. INT. READ/WRITE DENIED	LOCKED, ID1, ATARS READ/WRITE DENIED	LOCKED, ID2, BCAS READ/WRITE DENIED	LOCKED, ID2, COORD. INT. READ/WRITE DENIED	LOCKED, ID2, ATARS READ/WRITE DENIED	LOCKED, ID1, BCAS READ/WRITE GRANTED
		UNLOCK	UNLOCKED	--	--	--	--	--	--
	COORD. INTERR.	LOCK	LOCKED, ID1, BCAS[1] READ/WRITE DENIED[2]	--	LOCKED, ID1, ATARS READ/WRITE DENIED	LOCKED, ID2, BCAS READ/WRITE DENIED	LOCKED, ID2, COORD. INT. READ/WRITE DENIED	LOCKED, ID2, ATARS READ/WRITE DENIED	LOCKED, ID1, INT. READ/WRITE GRANTED
		UNLOCK	--	UNLOCKED	--	--	--	--	--
	UPLINKED ATARS CMD	LOCK	LOCKED, ID1, BCAS READ/WRITE DENIED	LOCKED, ID1, COORD. INT. READ/WRITE DENIED	--	LOCKED, ID2, BCAS READ/WRITE DENIED	LOCKED, ID2, COORD. INT. READ/WRITE DENIED	LOCKED, ID2, ATARS READ/WRITE DENIED	LOCKED, ID1, ATARS READ/WRITE GRANTED
		UNLOCK	--	--	UNLOCKED	--	--	--	--
THREAT ID2	OWN BCAS LOGIC	LOCK	LOCKED, ID1, BCAS READ/WRITE DENIED	LOCKED, ID1, COORD. INT. READ/WRITE DENIED	LOCKED, ID1, ATARS READ/WRITE DENIED	--	LOCKED, ID2, COORD. INT. READ/WRITE DENIED	LOCKED, ID2, ATARS READ/WRITE DENIED	LOCKED, ID2, BCAS READ/WRITE GRANTED
		UNLOCK	--	--	--	UNLOCKED	--	--	--
	COORD. INTERR.	LOCK	LOCKED, ID1, BCAS READ/WRITE DENIED	LOCKED, ID1, COORD. INT. READ/WRITE DENIED	LOCKED, ID1, ATARS READ/WRITE DENIED	LOCKED, ID2, BCAS READ/WRITE DENIED	--	LOCKED, ID2, ATARS READ/WRITE DENIED	LOCKED, ID2, COORD. INT. READ/WRITE GRANTED
		UNLOCK	--	--	--	--	UNLOCKED	--	--
	UPLINKED ATARS CMD	LOCK	LOCKED, ID1, BCAS READ/WRITE DENIED	LOCKED, ID1, COORD. INT. READ/WRITE DENIED	LOCKED, ID1, ATARS READ/WRITE DENIED	LOCKED, ID2, BCAS READ/WRITE DENIED	LOCKED, ID2, COORD. INT. READ/WRITE DENIED	--	LOCKED, ID2, ATARS READ/WRITE GRANTED
		UNLOCK	--	--	--	--	--	UNLOCKED	--

[1] NEXT STATE : LOCKED UNDER THREAT ID1, FOR BCAS

[2] REPLY : "READ/WRITE DENIED"

FIGURE L-3-1
STATE TRANSITION FUNCTION FOR THE CIR CONTROLLER, WITH TWO THREATS

directly into the coordination reply; the CIR in this case acts as a reply message buffer. If the CIR is in the LOCKED state, a CIR BUSY indication is read directly into the reply. This protocol is overriden if the CIR is busy but the sender ID of a received BCAS coordination interrogation has higher priority than own ID. In this case, a priority interrupt of the logic using the CIR is performed, the CIR is sent in a coordination reply, and the coordination interrogation is serviced. This logic is explained further in Subsection L-3.3. A schematic of the reply message switching operation is presented in Figure L-3-2. In the case when the CIR is free and available for readout into the reply, that readout action is simultaneous with locking the CIR, to allow the CIR to service the logic which handles the coordination interrogation data. (That logic is presented in Subsection L-3-3). If the sender is ATARS and the CIR is already locked, no reply at all is emitted, and the DABS sensor will continue to re-issue the interrogation in that same scan until a reply is received.

L-3.3 Detailed Coordination Logic

Logic which is to be executed upon reception of an interrogation from another system is presented in Figure L-3-3. It must be performed by aircraft equipped with a DABS transponder and display and by aircraft having full DABS-BCAS units. This logic is executed simultaneously with the operation of the reply message switching discussed in the previous subsection. The interrogation is examined in order to decide whether the sender is ATARS or a remote BCAS. In the former case, the ATARS coordination logic, presented in Figure L-3-4, is executed. A picture of the CIR is included in this figure for easy reference.

Since the logic in Figure L-3-3 is executed simultaneously with the reply message switching, the logic in Figure L-3-4 must first determine the position of the switch. If the switch was originally in the locked position, the CIR was busy when the interrogation was decoded, and no

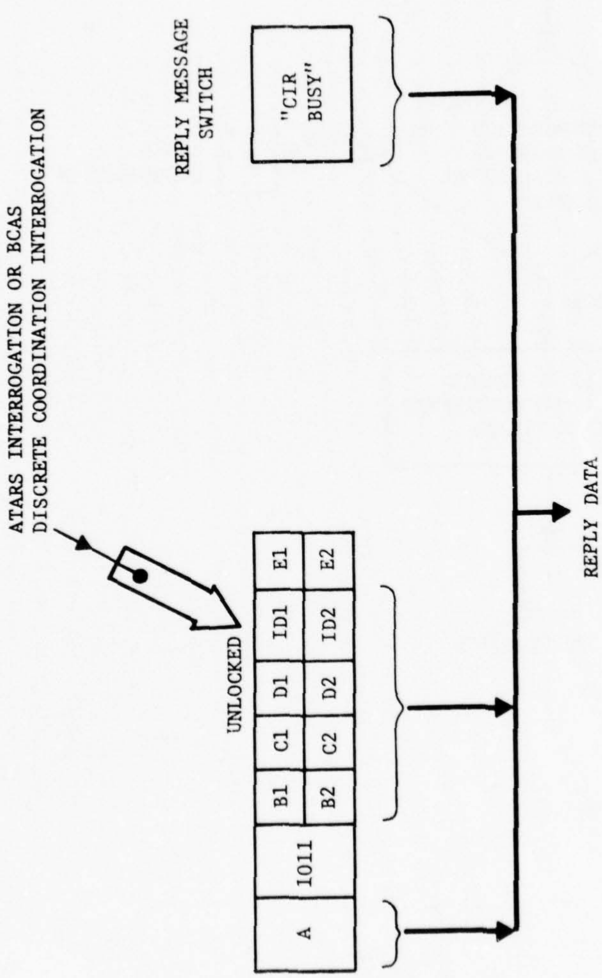


FIGURE L-3-2
REPLY MESSAGE SWITCHING

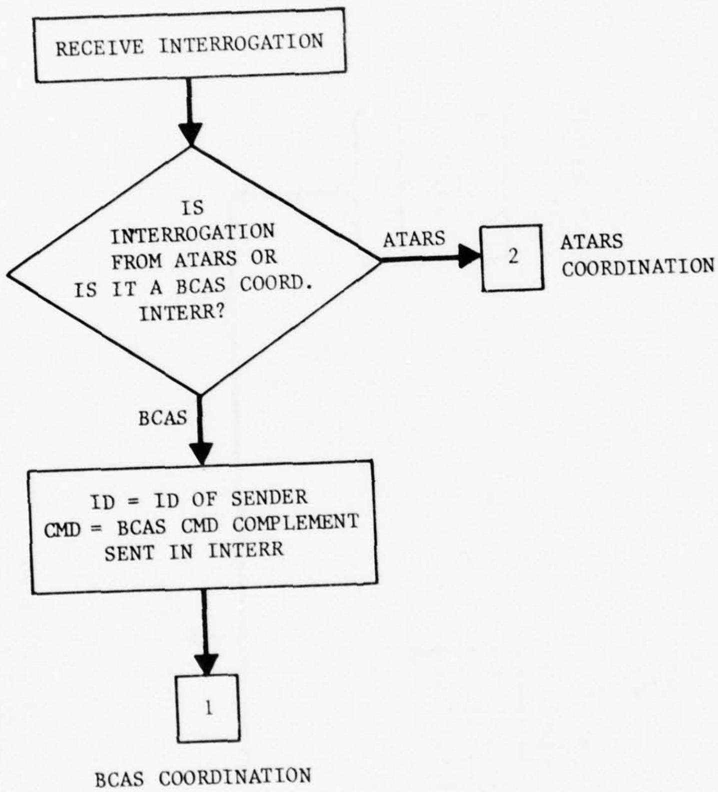


FIGURE L-3-3
DABS-BCAS LOGIC

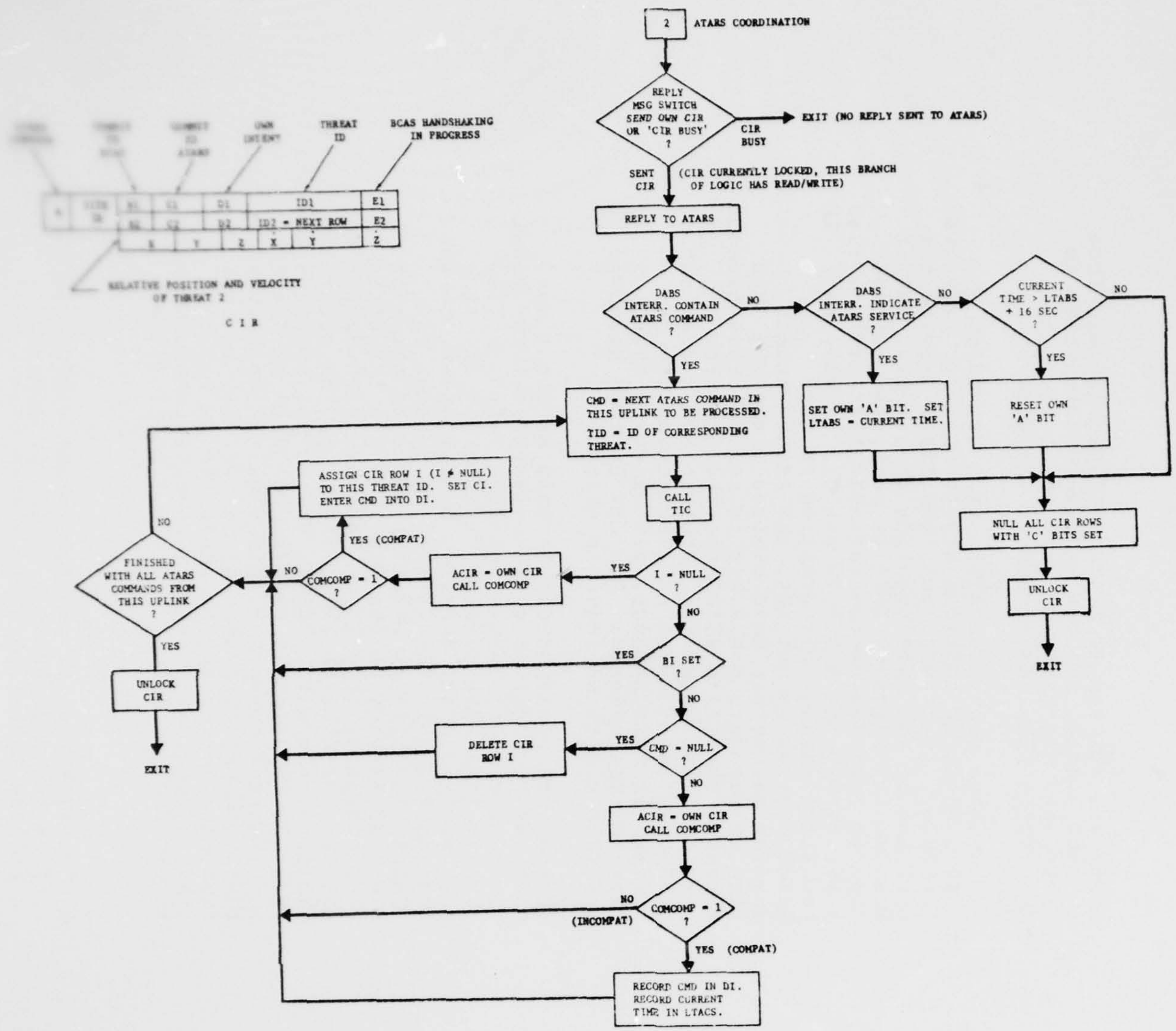


FIGURE L-3-4
ATARS COORDINATION LOGIC

reply was emitted to ATARS. If the CIR was free at that moment, its contents were downlinked to ATARS, and the CIR was simultaneously locked. This logic then has access to the CIR.

The message sent from ATARS is examined to determine if it contains any positive or negative commands. If it does not, the ATARS service bit position of the interrogation is checked, and if service is indicated (bit is set), the current time is recorded as the variable LTABS ("last time A bit set"); the A bit in own CIR is also set. If the ATARS service bit position in the interrogation is not set, and if 16 seconds (system parameter) have elapsed since the last time it was set, own A bit is reset. This timeout prevents the CIR's ATARS service bit from remaining set after the aircraft has passed out of DABS coverage. Since no ATARS commands are present in this message, all existing ATARS commands are deleted. The CIR is then unlocked and this branch of logic is exited.

If the interrogation did contain at least one positive or negative ATARS command, set CMD equal to the first one in the message. Also set TID (threat identity) equal to the threat ID, also sent in this ATARS message, corresponding to the command.* TID is then passed to routine TIC (Threat Identity Correlator) which compares it to every ID already in the CIR. If the threat is DABS equipped, this ID is just its DABS 24-bit ID, and the correlation is trivial. If the threat is equipped only with ATCRBS, TID is its position and velocity relative to own (as measured by ATARS), and TIC must correlate this with the corresponding ATCRBS threat ID's already in the CIR, if any. This correlation may be performed in a least-squares sense with a reasonableness check. If TIC finds a match, it sets I equal to the

---

* The ATARS uplink message format will be altered from the experimental model, in order to include threat identity information.

corresponding CIR row number; if no match is found, I is given a null value. Control is then returned to the point at which TIC was called.

If I is not null, then the 'B' bit (commit to BCAS) is checked to see which system has already entered the command for evading this threat. If that system is ATARS and CMD is null, then row I is deleted from the CIR. If the system is ATARS and the command is not null, then a check is performed to determine whether the ATARS command received on this uplink is compatible with all other commands appearing in the CIR. Although an ATARS command remains the same from scan to scan with high probability, ATARS has logic which recomputes commands and alters them in certain situations (e.g., non-response of the threat aircraft). If a new BCAS command (for evading some other threat) had appeared in the CIR after the previous downlink, ATARS would not have been able to use it as a command selection constraint. To check for compatibility, the ATARS command received on this uplink (CMD), together with an image of the CIR (ACIR), is passed to routine COMCOMP ("command compatibility"). This routine compares CMD with all D fields (own intents) already in the CIR. COMCOMP uses the command compatibility matrix presented in Table L-3-2 to make this determination. If no incompatibility is found, COMCOMP returns a value of 1. The ATARS command is then recorded in DI, and the current time is recorded in variable LTACS ("last time ATARS command set"); LTACS is used as a timeout in case own aircraft leaves the ATARS service zone through the DABS coverage floor. If COMCOMP detects an incompatibility, it returns the value 0, and the ATARS command is rejected. When ATARS examines the CIR downlinked to it, it will also discover the incompatibility (using a routine similar to COMCOMP), and it will deduce that its command was rejected by own aircraft. ATARS must then reselect the command in a way compatible with the downlinked CIR, and it is forced to wait until the next scan to deliver it. The coordination logic then proceeds to the next ATARS command uplinked on this same interrogation.

If TIC returns a null value of I, then this is the first command received from any system for evading the indicated threat. COMCOMP is used as before to check for compatibility. If no incompatibility is detected, a row in the CIR is allocated to the indicated threat, CI is set (committing to ATARS for separation from this threat), and the ATARS command is written into the intent field D.

If any other ATARS command received on this uplink remains, it is processed. If not, the CIR is unlocked and this branch of logic is exited.

If the logic presented in Figure L-3-3 determines that the interrogation was a BCAS coordination interrogation, ID is set equal to the DABS ID of the sender (included in that interrogation), and CMD is set equal to the BCAS command complement, also sent in the interrogation. The logic presented in Figure L-3-5 is then executed.

A check is first made to determine whether the DABS ID of the sender is of higher priority (is larger) than own DABS ID. If it is not, a reply is emitted (containing own CIR) if own CIR is not busy at the moment, or a CIR BUSY message is emitted if it is busy. If the sender's ID is of higher priority than own ID, own BCAS logic's use of the CIR (Figure L-3-5) is interrupted if that logic is in fact currently being serviced by the CIR. The reason for this is that own BCAS might simultaneously be attempting to coordinate with this threat, and it is necessary to prevent both units from hanging up indefinitely. The priority interrupt has the effect of tie-breaking in this case. The CIR is then sent in a coordination reply.

When this branch of logic is given access to the CIR by either of these paths, routine TIC ("threat identity correlator") is called. If it returns a null value of I (no command has yet been posted for evading the indicated threat), a check is made of both aircraft's 'A' bits. If they are both set, ATARS is responsible for resolving this conflict and the BCAS command is rejected. If at

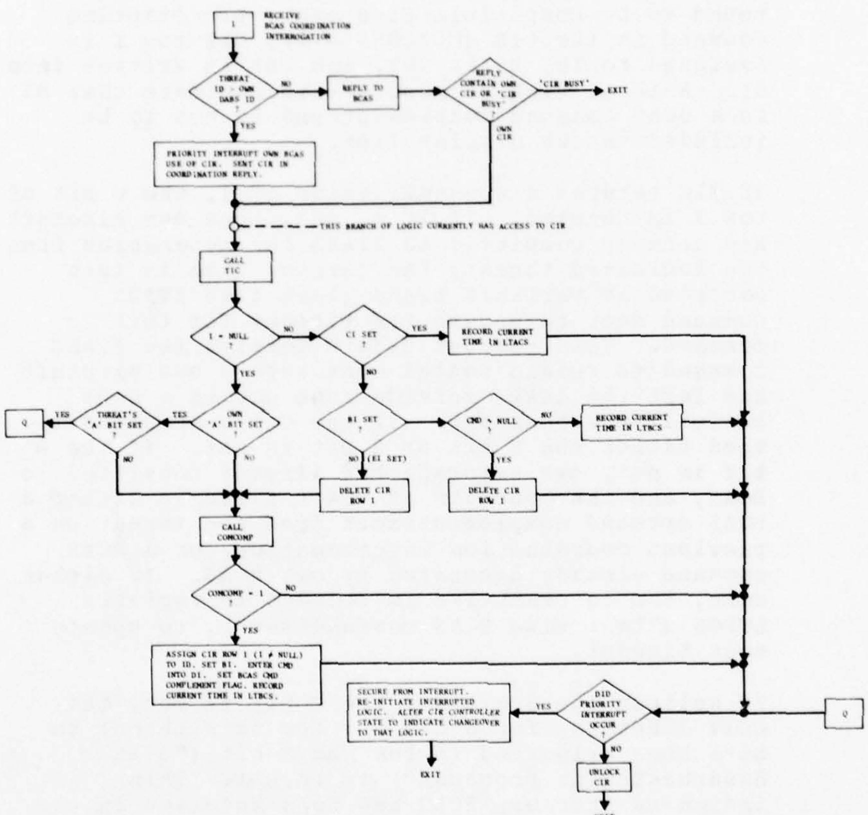


FIGURE L-3-5
BCAS COORDINATION LOGIC

least one of them is not set, routine COMCOMP ("command compatibility") is called. If CMD is found to be compatible with every pre-existing command in the CIR (COMCOMP = 1), CIR row I is assigned to ID, BI is set, and CMD is written into DI. A local flag is also set to indicate that DI is a BCAS command complement and is not to be included in own display list.

If TIC returns a non-null value of I, the C bit of row I is checked. If it is set, then own aircraft had already committed to ATARS for separation from the indicated threat; the current time is then recorded in variable LTACS (last time ATARS command set) to update the timeout for this command. This timeout update permits the ATARS command to remain posted even though own aircraft has left the ATARS service zone across a DABS surveillance boundary. If the C bit is not set, then either the B bit or E bit is set. If the B bit is set, own aircraft had already committed to BCAS, and the contents of the D field is either a BCAS command complement sent from the threat on a previous coordination interrogation, or a BCAS command already generated by own BCAS. In either case, the current time is recoded in variable LTBCS ("last time BCAS command set"), to update that timeout.

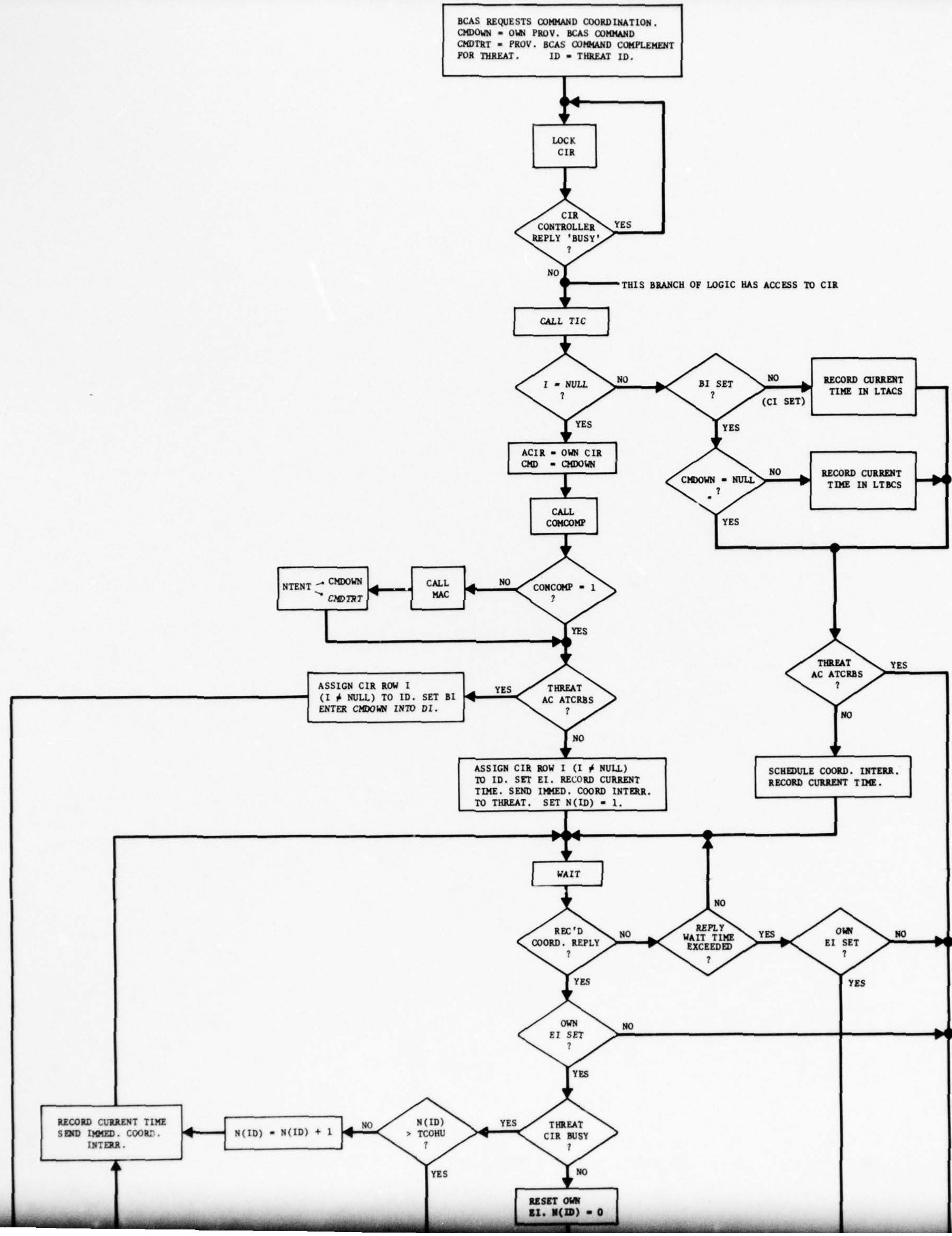
If neither the B bit nor the C bit is set, the only other way for a CIR row for this threat to have been allocated is for the E bit ("BCAS handshaking in progress") to be set. This indicates that own BCAS had been involved in coordination and was interrupted by the present logic. In this case, the CIR row is deleted and CMD is sent to COMCOMP to determine compatibility, just as if TIC had returned a null value of I.

When this logic is completed, a check is made to determine if it had begun via a priority interrupt. If so, the interrupted logic is re-initiated (not continued at the interruption point) with access to the CIR being handed over to it. If no priority interrupt had occurred, the CIR is unlocked and this logic is exited.

Logic to be executed when own BCAS requests command coordination is presented in Figure L-3-6. As discussed in Subsection L-3.1, BCAS sends the threat ID and the provisional command set (NTENT) to this logic. The first task is to separate NTENT into own provisional command (CMDOWN) and the complementary command for the threat (CMDTRT). A loop then sends lock requests to the CIR controller until access is granted.

The threat ID is then sent to routine TIC. If a pre-existing CIR row is found (I is not NULL), the B bit is checked to determine which system is responsible. If that system is ATARS, the ATARS timeout variable LTACS ("last time ATARS command set") is updated to the current time. If BCAS is the responsible system and CMDOWN is not null, the BCAS timeout variable LTBCS ("last time BCAS command set") is updated to the current time. An intracomputer message from BCAS with a null CMDOWN implies that BCAS desires to drop commands for this target, which is no longer a threat; LTBCS is therefore not updated in this case.

Whichever system is responsible, a coordination interrogation is sent to the target aircraft if it is equipped at least with a DABS transponder and display (a coordination interrogation would be meaningless to an ATCRBS transponder or to a DABS transponder without a display, which is treated as if it were ATCRBS). The current time is also recorded in order to avoid getting hung up waiting for a coordination reply that is not forthcoming. If CMDOWN = null, implying that CMDTRT = null, CMDTRT is nevertheless sent to the target aircraft in a coordination interrogation. That aircraft would then use the null BCAS command complement to delete its CIR row corresponding to own. It is not necessary to transmit an immediate coordination interrogation because I not being null implies that coordination has already been performed and this coordination interrogation will be used by the threat simply to update its timeout of its command (or command complement), or to drop an old command complement. Since this logic does not differentiate on the basis of the B or C bit


BCAS REQUESTS COMMAND COORDINATION. CMDOWN = OWN PROV. BCAS COMMAND CMDTRT = PROV. BCAS COMMAND COMPLEMENT FOR THREAT. ID = THREAT ID.
LOCK CIR
CIR CONTROLLER REPLY 'BUSY' ?
YES
NO
THIS BRANCH OF LOGIC HAS ACCESS TO CIR
CALL TIC
I = NULL ?
NO
YES
BI SET ?
NO
(CI SET)
RECORD CURRENT TIME IN LTACS
YES
CMDOWN = NULL ?
NO
RECORD CURRENT TIME IN LTBCS
YES
ACIR = OWN CIR
CMD = CMDOWN
CALL COMCOMP
CONCOMP = 1 ?
NO
CALL MAC
NTENT → CMDOWN
→ CMDTRT
YES
THREAT AC ATCRBS ?
YES
ASSIGN CIR ROW I (I ≠ NULL) TO ID. SET BI ENTER CMDOWN INTO DI.
NO
ASSIGN CIR ROW I (I ≠ NULL) TO ID. SET EI. RECORD CURRENT TIME. SEND IMMED. COORD INTERR. TO THREAT. SET N(ID) = 1.
THREAT AC ATCRBS ?
YES
NO
SCHEDULE COORD. INTERR. RECORD CURRENT TIME.
WAIT
REC'D COORD. REPLY ?
NO
REPLY WAIT TIME EXCEEDED ?
NO
YES
OWN EI SET ?
NO
YES
YES
OWN EI SET ?
NO
YES
THREAT CIR BUSY ?
YES
N(ID) > TCOHU ?
NO
N(ID) = N(ID) + 1
RECORD CURRENT TIME SEND IMMED. COORD. INTERR.
YES
NO
RESET OWN EI. N(ID) = 0

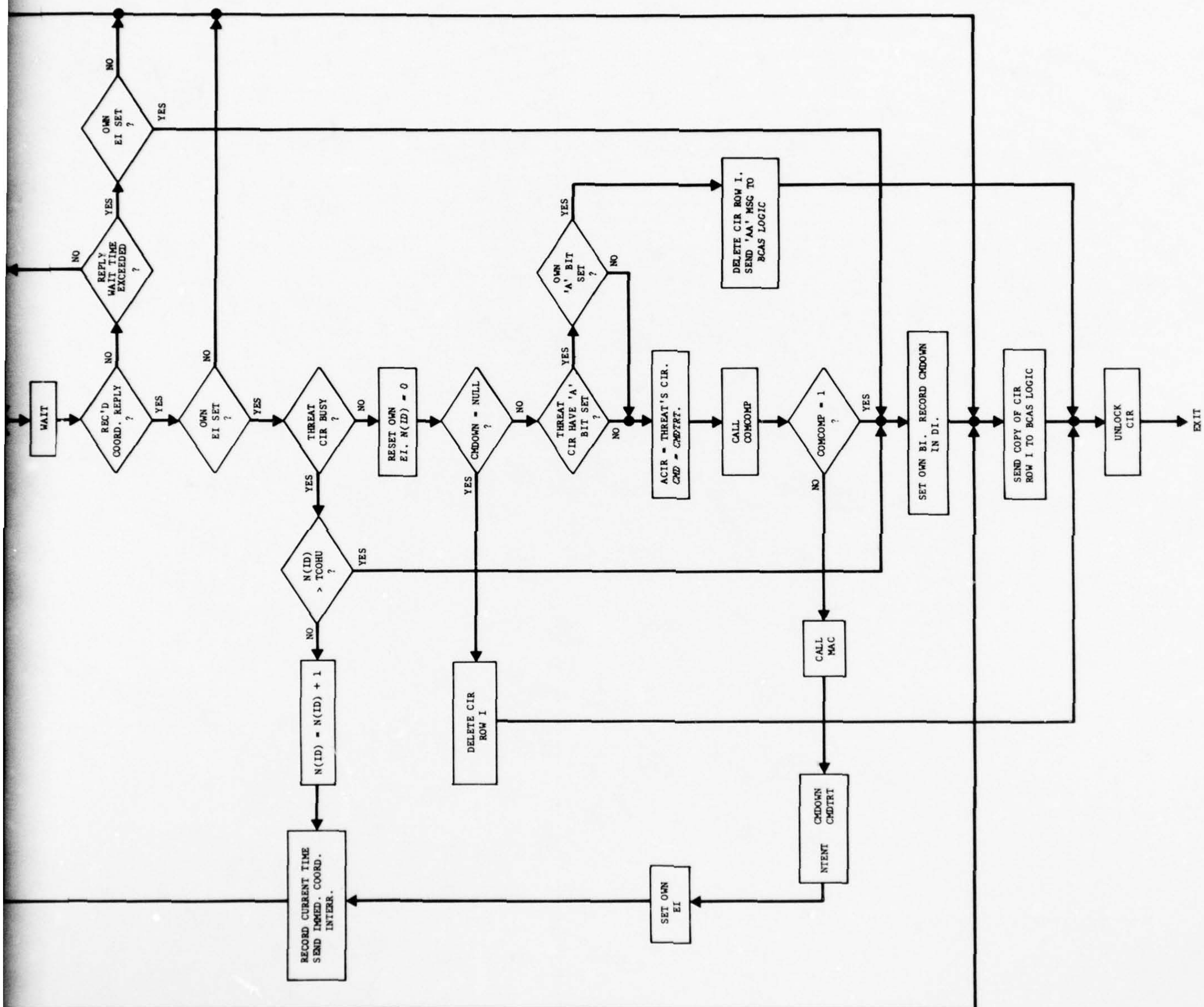


FIGURE L-3-6
BCAS COORDINATION LOGIC

2

being set, the coordination interrogation is sent to the threat regardless of which system is responsible for this conflict. If that system is ATARS, the coordination interrogation enables the threat aircraft to maintain its ATARS command as long as own BCAS perceives a hazard, in the case when the threat drops out of ground surveillance before the danger has been eliminated. If the responsible system is BCAS but the threat is equipped only with DABS and a CAS display, the continued coordination interrogation permits the threat to maintain its BCAS command complement associated with own, so that ATARS would not send it a command (to evade some threat other than own) which thwarts own's resolution.

If TIC returns a null value of I, routine COMCOMP is called to make sure that own provisional command is compatible with own CIR. If an incompatibility is detected (COMCOMP returns a value of 0), a multi-aircraft logic routine (MAC) is called to reselect the provisional command set. MAC returns a value of NTENT, which must once more be separated into own provisional command and its provisional command complement.

If the threat aircraft is ATCRBS-equipped, BCAS is designated the responsible system, and this logic is exited. If the threat has DABS, it is necessary to perform air-to-air handshaking. A CIR row is allocated to the threat's ID and the E bit is set to indicate that BCAS handshaking is in progress. A local counter N(ID), indexed on the ID of the threat, is also initialized, in order to prevent against looping indefinitely if the threat's CIR is malfunctioning and remains locked. A coordination interrogation (containing own DABS ID, own A bit, and the BCAS provisional command complement CMDTRT) is immediately transmitted to the threat. If no reply is received by the time the reply wait interval has elapsed, own computer commits to BCAS for separation from the threat (if own E bit is set; if it is not set, coordination had previously been accomplished and the logic is simply exited).

If a coordination reply is received before the reply wait interval has elapsed, the E bit is similarly checked. If this is indeed the initial handshaking cycle, the coordination reply is examined to determine whether the threat's CIR was busy at the moment it received own's coordination interrogation. If it was busy, the same coordination interrogation is immediately retransmitted, provided that the number of retransmissions is not excessive. An excessive number of coordination interrogation retransmissions is reached when N(ID) > TCOHU (threat CIR is obviously hung up). If this number is found to be excessive, own computer commits to BCAS. If not, N(ID) is incremented to reflect the current retransmission.

If the coordination reply contained the threat's CIR, EI and N(ID) are reset. CMDOWN is then checked to determine whether it is null, indicating that BCAS is dropping commands and the coordination interrogation was only to inform the target aircraft of this fact. If CMDOWN is in fact null, the CIR row corresponding to this target is deleted, and the logic is exited. If CMDOWN is not null, both own and threat's A bits are checked. If both are set, ATARS is responsible for assuring separation of this pair and BCAS must suppress its commands. The CIR row associated with this threat is deleted and the logic is exited, while sending an 'AA' message ("both own and threat are being protected by ATARS") to own BCAS logic.

If at least one aircraft in this pair does not have its A bit set, the threat's CIR and the BCAS provisional command complement sent to the threat in own's coordination interrogation, are sent to routine COMCOMP. If COMCOMP returns a value 0, it is deduced that the threat rejected the provisional command complement, since the threat will have used an identical COMCOMP logic to test for compatibility. The multi-aircraft logic MAC is then called, and it uses the threat's CIR, own CIR and own's track of the threat, to select a new command set which is universally compatible. Upon

return of control from MAC, another coordination interrogation is immediately sent, with the new command complement.

If COMCOMP returns a value 1, it is deduced that the threat accepted the command complement. Own computer then commits to BCAS. When exiting this logic, a final copy of the CIR row assigned to ID is sent to the BCAS logic.

Several auxiliary functions have been omitted from the preceding flow charts for the sake of clarity. DABS interrogations from ground sites will contain not only commands and A bits, but also Proximity Warning Indications (PWI's); such nearby target data are also available from BCAS, which refers to them as Intruder Position Data (IPD's). (DABS interrogations may also include air traffic control (ATC) messages and weather data, which are not treated in this document). In order to assure uniqueness of nearby target indications on the cockpit display, the following filter has been established. If own A bit is set, only ATARS-originated PWI's will be presented to the pilot. BCAS-originated IPD's are presented when own A bit is not set. BCAS will periodically check own A bit (see Table L-3-1, own 'A' bit request message), and display or inhibit the IPD's it generates.) For a similar reason, BCAS-originated vertical speed limit commands (VSL's) are not filtered; they are displayed at all times.

Certain actions taken by the CIR controller should also be clarified. When responding to an ATARS message from the ground, the aircraft will reply with own CIR if available, and will not reply at all if the CIR is locked. When responding to a BCAS coordination interrogation, the aircraft will reply with own CIR if available, and will reply with a CIR BUSY message if the CIR is locked. When responding to own BCAS request for coordination as when an intra-computer message from Table L-3-1 is received, that request is honored immediately if the CIR is available. If the CIR is locked, the request is held in a WAIT

state until it becomes free, and is then honored. This is done in order to free the BCAS logic from the need to periodically re-issue coordination requests when the CIR is unavailable.

As described in Appendix K, the cockpit display information can originate from either the BCAS logic or the ATARS-BCAS interface, or both. (Uplinked ATC messages are also displayed, but this activity lies outside the scope of this document.) These functions send display requests (post information, delete information, alter information) to a stack called the Display Request Queue (see Figure L-3-7). An activity called the Display Function accomodates these requests one at a time, creating display vectors which it writes into the Display List. The Display Driver program reads these vectors and transforms them into display commands for the cockpit display.

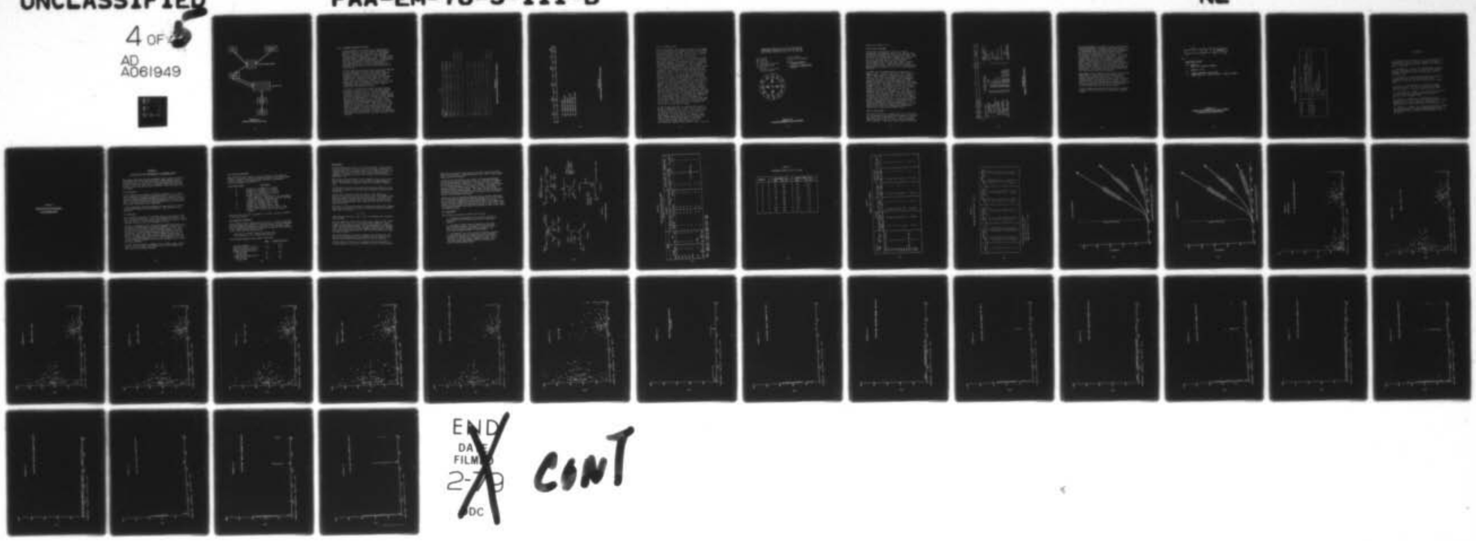
Whenever a branch of coordination logic adds an ATARS command to the CIR, or deletes one from it, it must also send a corresponding display request to the Display Request queue. The request consists of the variables IDENT (threat ID), DPLY (collision avoidance maneuver command), FLSHFL (a bit which is set if a flashing PWI is desired), and the B and C bits of that CIR row. A null value of DPLY is recognized by the Display Function as a symbol deletion request. The coordination logic does not send display requests to the Display Request Queue, when the command being altered originates from BCAS. Instead, when the coordination logic is exited and an intra-computer message is sent to the BCAS logic, that logic generates any necessary display requests.

Finally, an endless loop in the CIR controller must cycle through the variables LTACS (last time ATARS command set) associated with each CIR row, in order to delete commands that have not been updated recently enough.

AD-A061 949 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C OFFIC--ETC F/G 17/7
FAA BCAS CONCEPT. VOLUME III B. APPENDICES F - M.(U)
APR 78 E J KOENKE

UNCLASSIFIED FAA-EM-78-5-III-B NL

4 OF 5
AD
A061949



END
DATE
FILMED
2-79
DDC

CONT

SIFIED

4 OF

AD
A061949

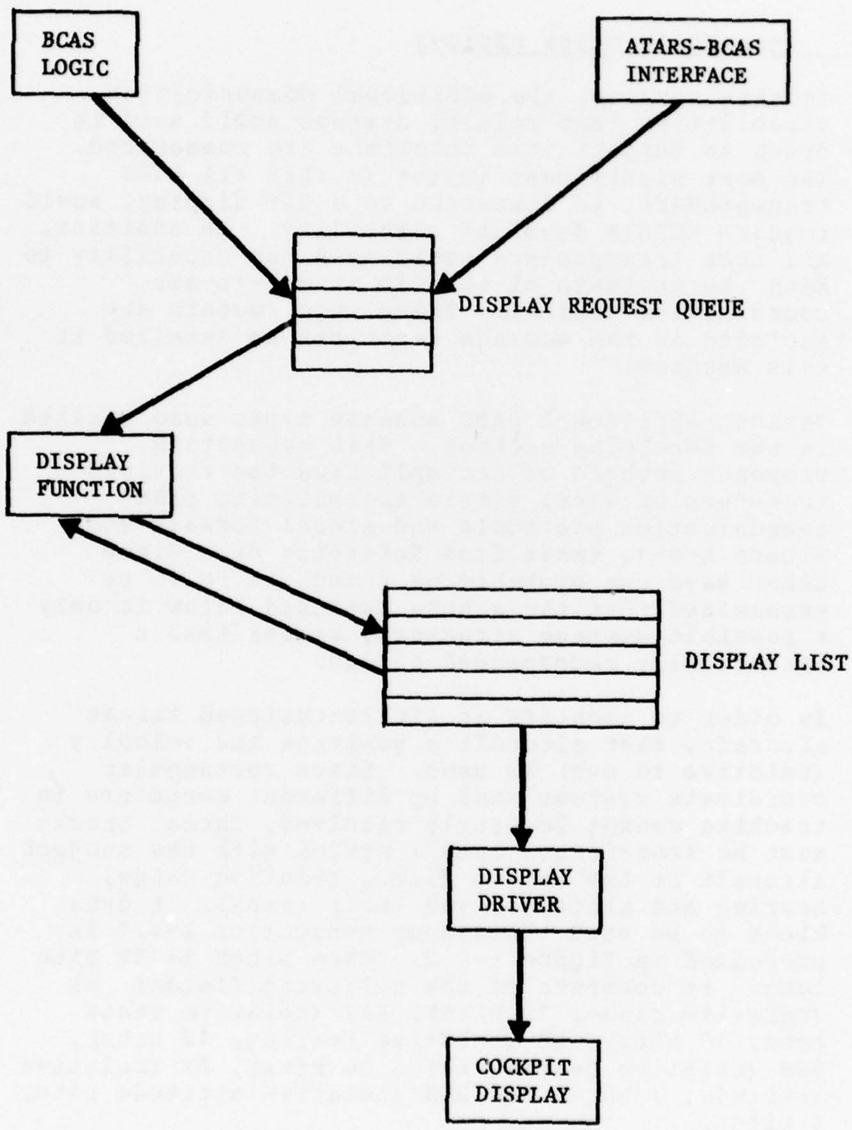


FIGURE L-3-7
DISPLAY INFORMATION FLOW

L-4. IMPACTS ON OTHER DESIGNS

In this section, the additional communication capabilities that related systems would need in order to support this interface are summarized. The most significant impact is that all DABS transponders, if connected to a CAS display, would require COMM-B downlink capability. In addition, all such transponders would need the capability to send the contents of the CIR in air-to-air coordination replies. These requirements are included in the message descriptions detailed in this section.

Various additional DABS message types were implied in the foregoing section. This subsection proposes methods of accomplishing the required transfers of data, within the existing DABS communication protocols and signal formats (see Figure L-4-1, taken from Reference 6). Since other ways can probably be found, it is to be emphasized that the scheme outlined below is only a possible message structure, rather than a specifically recommended design.

In order to identify an ATCRBS-equipped threat aircraft, that aircraft's position and velocity (relative to own) is used. Since rectangular coordinate systems used by different computers in tracking cannot be easily resolved, threat tracks must be transformed into a system with the subject aircraft at the origin (i.e., relative range, bearing and altitude, and their rates). A data block to be used throughout subsection L-4.1 is presented in Figure L-4-2. This block is 54 bits long. It consists of the following fields: RR (relative range, 12 bits), RRR (relative range rate, 10 bits), RB (relative bearing, 12 bits), RBR (relative bearing rate, 10 bits), RZ (relative altitude, 7 bits) and RZR (relative altitude rate, 3 bits).

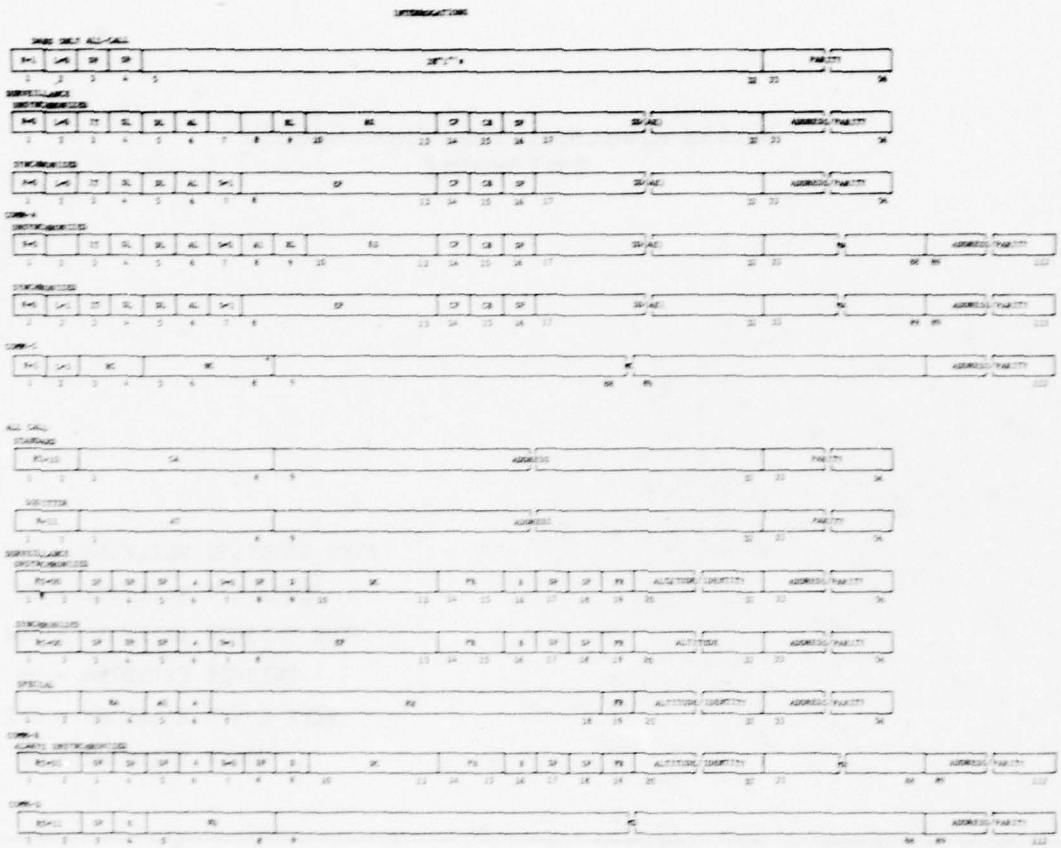


FIGURE L-4-1
DABS INTERROGATION AND REPLY DATA FORMATS

RR	RRR	RB	RBR	RZ	RZR
-12-	-10-	-12-	-10-	-7-	-3-

RR = RELATIVE RANGE
RRR = RELATIVE RANGE RATE
RB = RELATIVE BEARING
RBR = RELATIVE BEARING RATE
RZ = RELATIVE ALTITUDE
RZR = RELATIVE ALTITUDE RATE

FIGURE L-4-2
ATCRBS THREAT RELATIVE TRACK BLOCK

L-4.1 Ground-to-Air

The most commonly used uplink message is for ATARS to set/reset the A bit (ATARS service) in aircraft entering/leaving the ATARS service zone. A single message bit would suit this purpose, and a spare position exists in the SD field of the surveillance interrogation. For example, SD bits 17-20=0010 can mean set A bit, and SD = 1000 can mean reset A bit. The uplink message for sending an ATARS command to an aircraft can be created by modifying the bit assignments shown in Figure L-4-3 (taken from Reference 7). This figure shows a section of COMM-A interrogation, and could be used with the interface design presented in this document, except that it is missing the ID of the threat aircraft. The TF field is a system test flag, the G bit is for gong (an audible alarm), field PF indicates flashing PWI's and fields PL-1 through PL-5 indicate PWI positions. It is felt that in the event of a command, the pilot will not be overly concerned with possible one position changes in non-threat PWI's and that it would not hamper safe resolution of the conflict if the PWI's remain at their original position (except for the one corresponding to the threat aircraft which stimulated the command). Therefore, bits 54 through 88 can be used to transmit the 24 bit DABS ID of the threat aircraft causing the command, and the corresponding PWI. Additional ID's and PWI's for simultaneous threats can be uplinked on successive COMM-A interrogations in the same dwell of the DABS main beam, with bit RL (reply length, see Figure L-4-1) directing the transponder to reply with a surveillance reply.

If the threat aircraft is equipped only with an ATCRBS transponder, it is necessary to send its relative track block as an ID. Since this block is 54 bits long, it will not fit in bits 54 through 88. Letting the first 24 bits of this field being all zero indicate an ATCRBS threat, this COMM-A interrogation must be followed by another one (on the same dwell of the DABS interrogation beam), which contains the corresesonding relative track block in the 56 bit MA

AR	MDES	DDES	AX	FAX	TF	G	PF	PL - 1	PL - 2	PL - 3	PL - 4	PL - 5
	111	0001	-9-		-2-		-5-	-6-	-6-	-6-	-6-	-6-
32	36	40	49		52		58	64	70	76	82	88

AR = Ackn. Request

MDES: must be 111

DDES: must be 0001

AX: energize symbol according to bit

FAX = Flash energized symbols

TF = Test Field:

00 not test, PL's are cumulative

01 light all AX and PWI

10 flash all AX and PWI

11 no test, PL's are not cumulative

G = Gong

PF = Flash PWI light addressed by corresponding PL field

PL - 1 through PL - 5 = energize PWI light which agrees with binary code in any PL field

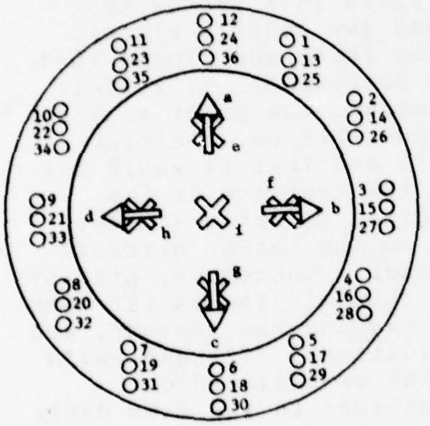


FIGURE L-4-3
ATARS EXPERIMENTAL UPLINK FORMAT

field (see Figure I-4-1).

L-4.2 Air-to-Ground

As discussed in earlier sections, a DABS transponder supplemented with a CAS display must be able to downlink the contents of the CIR. The transponder's surveillance reply would contain bit 16 = '1', indicating that a COMM-B message is waiting; the DABS sensor would thereupon reinterrogate (on the same scan) with a request for a COMM-B reply. Successive COMM-B reply blocks, one for each CIR row, can be sequentially downlinked by having bit 16 set on each block but the last.

A format for the COMM-B reply is presented in Figure L-4-4. Again, this figure shows only the 'MB' segment (bits 33 through 88) of a COMM-B reply. This figure is largely self-explanatory. If field TT = 00, indicating a threat equipped only with ATCRBS, it is understood that this COMM-B transmission shall be immediately followed by another one containing the relative track block (Figure L-4-2). If several rows of the CIR are filled, they are downlinked in successive COMM-B replies on the same scan, according to the protocol outlined in Reference 6. This protocol prevents the loss of a COMM-B message segment due to RF or other interference. The interrogator is required to acknowledge the receipt of a COMM-B transmission by setting bit 15 (CB: clear COMM-B) in its next interrogation in the sequence (a new COMM-B transmission cannot be emitted without being so requested by an interrogation). If the interrogator misses a COMM-B transmission, CB is reset in the next interrogation), requesting repetition of the missed COMM-B reply.

L-4.3 Air-to-Air

The first air-to-air transmission to be discussed is the coordination interrogation which is emitted by a BCAS and is addressed to a threat aircraft (when the threat has at least a DABS transponder with display). This interrogation must convey the

DSRC	SID	B	C	D	TID	TT	DS	
1000	0101			0011				UNDEFINED

BIT 33, 37, 41, 42, 43, 47, 71, 73, 74, 88

DEFINITION OF FIELDS

DSRC: UNIQUE CODE USED TO IDENTIFY BCAS TRANSMISSIONS

SID: SITE ID FIELD USED FOR ATARS MULTISITE COORDINATION

B: INDICATES COMMITMENT TO BCAS FOR SEPARATION FROM THREAT

C: INDICATES COMMITMENT TO ATARS FOR SEPARATION FROM THREAT

(B AND C CANNOT BOTH BE SET FOR A PARTICULAR THREAT)

D: OWN INTENT (MANEUVER FOR EVADING THIS THREAT)

D	INTENT
0001	CLIMB
0010	DON'T CLIMB
0011	DESCEND
0100	DON'T DESCEND
0101	TURN RIGHT
0110	DON'T TURN RIGHT
0111	TURN LEFT
1000	DON'T TURN LEFT
1001	LEVEL OFF
1010	DON'T CLIMB > 500 FT/MIN
1011	DON'T DESCEND > 500 FT/MIN
1100	DON'T CLIMB > 1000 FT/MIN
1101	DON'T DESCEND > 1000 FT/MIN
1110	DON'T CLIMB > 1500 FT/MIN
1111	DON'T DESCEND > 1500 FT/MIN

TID: THREAT ID (DABS 24-BIT ADDRESS IF THREAT IS DABS-EQUIPPED) (ALL ZEROS IF TT = 00)

TT: THREAT TYPE

TT	THREAT TYPE
00	ATCRBS
01	DABS
10	DABS WITH DISPLAY
11	BCAS

DS: DESENSITIZATION STATUS

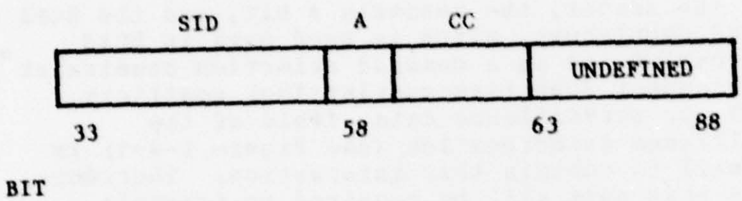
DS	STATUS
0	ALL PARAMETERS NORMAL
1	DESENSITIZING IN EFFECT

FIGURE L-4-4
FORMAT FOR THE BCAS MB FIELD

ID of the sender, the sender's A bit, and the BCAS command complement, which is used both in BCAS tie-breaking and as a command selection constraint in subsequent (but time-overlapping) conflicts. The SD, or surveillance data, field of the surveillance interrogation (see Figure L-4-1) is too small to contain this information. Therefore, a DABS-BCAS unit will be required to transmit a COMM-A interrogation for coordination with a threat. The ID and A bit of the sender and the BCAS command complement can be easily fit into the MA field (see Figure L-4-5), using the intent codes listed in Figure L-4-4 for the BCAS command complement. For normal active ranging, BCAS can use the surveillance interrogation.

The format of the COMM-B coordination reply can be identical to that discussed in Section L-4.2, except that an additional code is required to indicate whether the CIR was busy at the time the coordination interrogation was received. As in Section L-4.2, the reading out of several CIR rows can be accomplished by successive coordination interrogation/coordination reply cycles.

A chart summarizing the additional data transfers required for the interface is presented in Table L-4-1.



DEFINITION OF FIELDS

SID: SENDER ID
(DABS 24-BIT ADDRESS OF SENDER)

A: SENDER'S 'A' BIT

CC: COMMAND COMPLEMENT FOR RECIPIENT
(SAME CODING AS 'D' FIELD, FIGURE 4-4, MINUS VSL CODES)

FIGURE L-4-5
FORMAT FOR THE MA FIELD IN A BCAS COMM-A COORDINATION INTERROGATION

TABLE L-4-1

ADDITIONAL MESSAGES REQUIRED FOR INTERFACE

GROUND TO AIR	1. SET (RESET)"A" BIT 2. ID OF THREAT WHEN SENDING COMMAND (RELATIVE TRACK OF THREAT IF THREAT IS ATCRBS)
AIR TO GROUND	1. CONTENTS OF CIR (ON EVERY REPLY)
AIR TO AIR	INTERROGATION 1. ID OF SENDER 2. SENDER'S "A" BIT 3. BCAS COMMAND COMPLEMENT REPLY 1. CIR

RFFERENCES

1. McFarland, A., Horowitz, B., A Description of the Intermittent Positive Control Concept, the MITRE Corporation, McLean, Virginia, FAA-EM-74-1, MTR-6587 Rev. 1, July 1975.

2. McFarland, A., "Multi-Site Intermittent Positive Control Algorithms for the Discrete Address Beacon System," The MITRE Corporation, McLean, Virginia, September 1974.

3. Schuchman, L., "An Active Beaon-based Collision Avoidance System Concept (BCAS)," The MITRE Corporation, McLean, Virginia, FAA-EM-74-4, October 1975.

4. Clark, J., McFarland, A., "Initial Collision Avoidance System," The MITRE Corporation, METREK Division, McLean, Virginia, MTR-7532, April 1977.

5. Drouilhet, P., "DABS: A System Description," MIT Lincoln Laboratory, Lexington, Massachusetts, FAA-RD-74-189, December 1974.

6. Welch, J., Robeck, P., "Proposed Technical Characteristics for the Discrete Address Beacon System (DABS)," MIT Lincoln Laboratory, Lexington, MAssachusetts, ATC-71, FAA-RD-77-143, September 1977.

7. Robeck, J., Welch, J., "Provisional Message Formats and Protocols for the DABS IPC/PWI Display," MIT Lincoln Laboratory, Lexington, Massachusetts, ATC-35, May 1974.

APPENDIX M

SIMULATIONS OF BCAS PERFORMANCE

vs. MEASUREMENT ERROR

APPENDIX M

SIMULATIONS OF BCAS PERFORMANCE VS. MEASUREMENT ERROR

This appendix describes two BCAS simulations which studied the effect of measurement error on CAS logic performance. These employed relative tracking referenced to own aircraft. The following sections describe: the two trackers; the logic used; the encounter geometries; simulation parameters; tabulated results; and conclusions. A set of scatter plots is attached.

M.1 The Tracker

In both simulations the target was tracked in relative x, y, $\dot{x}$, and $\dot{y}$ using conventional alpha-beta tracking with alpha = 0.4 and beta = 0.15. The first simulation modeled measurement noise with components independent and normally distributed in range and bearing (of the target to the BCAS). The second simulation modeled measurement noise with independent and normally distributed x and y components.

In both simulations, BCAS has knowledge of its own speed and "heading" (ground track heading, with wind neglected). These quantities were errorless.

M.2 CAS Logic

Both simulations were run with a modified version of the "passive" BCAS logic contained in MTR-7532. Level 3 (the desensitized version) of the logic was selected, with the miss distance threshold for positive commands increased from the 0.4 nmi in the document to 0.5 nmi.

The logic was augmented with a feature which automatically selects the horizontal or vertical plane for positive commands. A primary factor in the selection is the speed of the BCAS aircraft (speed of the other aircraft is not a factor when other is not BCAS-equipped, as in these simulations). Since the simulated BCAS aircraft was faster than the 150 knot threshold in the logic, vertical commands should usually be chosen. To compare these results with horizontal maneuvers, many runs in the second simulation were run twice: once normally and once with the logic threshold changed so as to force the automatic logic to select horizontal maneuvers.

The BCAS logic uses negative commands based on geometry alone, without regard to aircraft speed. This produces "don't turn" commands which effect many of the turning scenarios.

M.3 Encounter Geometries

These simulations were created to study two aspects of CAS logic performance: separation provided in collision situations, and false alarms in safe situations. The following table describes the geometries, which are illustrated in Figure M-1.

Scatter Plot Symbol	Description
A	Straight 45° convergence to collision
B	Straight 90° convergence to collision
C	Straight 135° convergence to collision
D	Straight 180° convergence to collision
E	Parallel courses 1 nmi apart: First simulation: BCAS turns 90° into unequipped. Second simulation: Unequipped turns 90° into BCAS.
F	Straight 45° crossing, 4000 ft. miss
G	Straight 90° crossing, 4000 ft. miss
H	Straight 135° crossing, 4000 ft. miss
I	Straight 180° crossing, 4000 ft. miss
J	Parallel courses, BCAS turns 90°, 4000 ft. miss
K	Initially 90° collision course, BCAS turns 45° behind.

Additional runs were made for geometries F through J modified to 6000 ft. (1 nmi) miss distance.

M.4 Simulation Parameters

Both simulations used a 180-knot BCAS aircraft vs. a 100-knot unequipped. Certain scenarios were repeated for 250 knot BCAS vs. 250 knot unequipped. The first simulation scattered 20 repetitions of each encounter. The second simulation used identical encounters, varying only the measurement noise. Other important parameters are:

Scan time = 4 seconds. Target report every scan.
Pilot response = 7 $\pm$ 1.5 seconds (uniform dist.)

The following parameters were normally distributed:

	Mean	Standard Deviation
Turn Rate (deg/sec)	3	0.3
Climb Acceleration (Ft/sec^2)	7.5	0.75
Descend Acceleration (Ft/sec^2)	7.5	0.75
Maximum Climb Rate (Ft/sec):		
180 knot BCAS	25	2.5
250 knot BCAS	30	3.0
Maximum Descent Rate (Ft/sec):		
180 knot BCAS	33.3	3.33
250 knot BCAS	30	3.0

M.5 Results

Table M-1 presents the results of the first simulation. Range and bearing measurement errors are listed in the first column. The separation provided by BCAS does not degrade until errors of 1000 feet in range and 3 degrees in bearing are reached. However, false alarms (positive commands) for straight courses increase in number for each increase in measurement error.

The turning collisions normally receive commands too late to be of help. However, when errors are large, an early negative command sometimes occurs. This provides an unexpected benefit by preventing a dangerous turn.

In the sixth line, errors in own speed and heading were added, but were insufficient to change the result previously obtained with perfect speed and heading.

The last line of Table M-1 shows the results of IPC (ATARS) logic applied to the same scenarios 50 nmi from the radar. The somewhat larger protective volume of the IPC Logic was reflected in the results, which show fewer failures and more false alarms than BCAS. Statistics were collected on the measurement errors generated in the IPC run. They are shown in Table M-2.

The results of the second simulation are presented in Table M-3. Measurement errors are presented in terms of Reconstructed Position Uncertainty (RPU), which is defined as

$$\sigma_x^2 + \sigma_y^2$$

using normally distributed x and y errors to approximate the measurement errors in BCAS

Table M-3 shows that "inner box" failures begin to appear at RPU = 1000 feet and reach a rate of 15 to 20 percent at RPU = 2000 feet. False alarms for the straight encounters increase approximately in proportion to RPU. The false alarms, however, are quite sensitive to the threshold used. With the logic set to alarm at 3000 feet miss distance, the same errors which produce many alarms for 4000 feet misses produce few alarms for 6000 feet misses.

Some of the statistics are shown in graphical form in Figure M-2. The curves show the probability of false alarms for 1 nmi misses vs. RPU, and show "late" alarms (Inner Box totals) vs. RPU for collisions.

Table M-3 shows the results to be consistent for either horizontal or vertical maneuvers; and for 180 vs 100 knot and 250 vs 250 knot aircraft.

Differences that appear in horizontal vs vertical alarm rates are due solely to the effects of random measurement noise. With a larger sample, these rates should converge.

To measure the contribution of the tracker in smoothing measurement errors, tracked data was collected for one run. This data is compared with predicted results in Table M-4. The collected data is averaged over an entire encounter, for one run per scenario. The measured values for the "straight" scenarios (all except E, J, and K) fall below the predicted values by 0 to 50 percent. The values for the turning encounters are considerably higher. This result confirms the predicted tracker performance for straight flight, and points out the tracking of turns as an area needing improvement.

Tracking in turns was studied in MTR-6541 (Mundra, Horowitz and Dellon, 1974). That report compared the Alpha-Beta tracker with the IPC tracker. The latter makes a heading correction upon declaration of a turn. Earlier work (to be published by Mitre) showed that a simple Kalman-type tracker for BCAS provides turn performance as good as that of IPC. Thus, two alternative tracker improvements are available to give earlier alarms in turning encounters.

M.6 Conclusions

The following conclusions are drawn from this work:

1. Increasing the measurement error causes an increase in false alarms before collision protection is significantly degraded.

2. The number of false alarms is sensitive to the logic miss distance threshold. To assess the true false alarm rate, an actual traffic model should be studied. This will enable optimum parameters to be determined.

3. Performance is poor for the turning collision simulated, in which aircraft are flying parallel in close proximity, followed by a sudden turn. The late alarm in this case is partly due to the slow tracker response to turns. One of the known tracker improvements should be implemented in order to provide earlier alarms

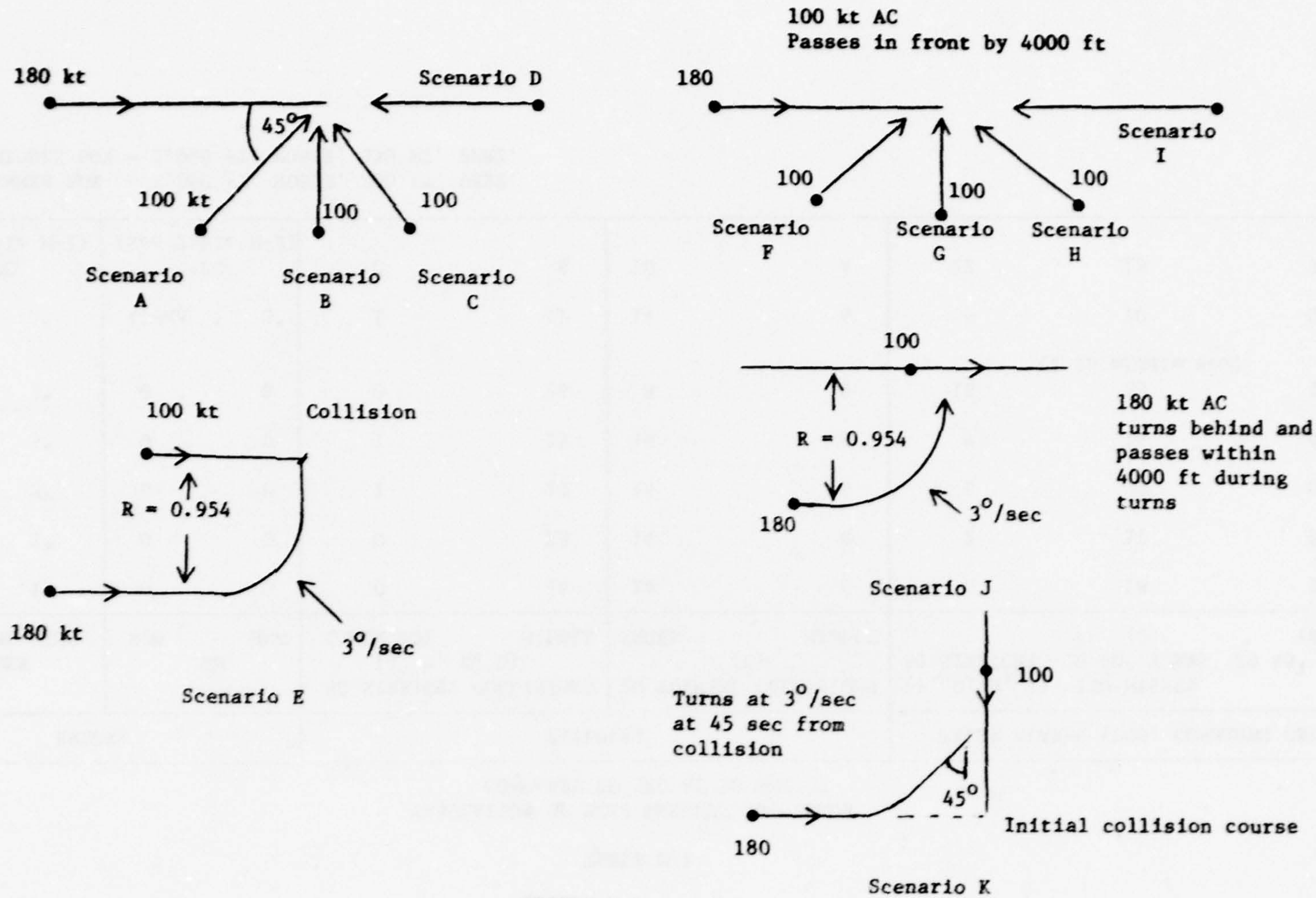


FIGURE M-1

ENCOUNTER GEOMETRIES

TABLE M-1

TABULATION OF BCAS RESULTS VS. ERROR
COMPARED TO IPC AT 50 NMI

ERRORS				FAILURES				FALSE ALARMS (POS. COMMANDS ONLY)		
TARGET		OWN		80 STRAIGHT COLLISIONS (A, B, C, D)		20 TURNING COLLISIONS (E)		(F, G, H, I) 120 MISSES		
RANGE	BEARING	SPD	HDG	INNER BOX	MIDDLE	INNER	MIDDLE	80 STRAIGHT	20 90° TURNS (J)	20 45° TURNS (K)
100'	.1°	0	0	0	14	14	6	0	18	0
100'	1°	0	0	0	13	14	6	1	17	0
100'	3°	0	0	1	17	14	6	6	20	0
500'	3°	0	0	1	15	14	6	9	16	0
1000'	3°	0	0	0	26	8	9	18	13 (1 in middle box)	1
100'	3°	1.8kn	3°	1	17	14	6	6	20	0
IPC (See Table M-2)		IPC (See Table M-2)		0	8	10	4	22	18	7

<u>NOTE:</u> INNER BOX = 1,000 FT. HORIZ, 200 FT. VERT.
MIDDLE BOX = 2,000 FT. HORIZ, 350 FT. VERT.

TABLE M-2

MEASUREMENT ERRORS IN IPC AT 50 NMI

SCENARIO	RANGE ERROR (FT.)		BEARING ERROR (DEG.)	
	MEAN	STD. DEV.	MEAN	STD. DEV.
A	-39	590	0.9	11.7
B	-43	493	0.3	11.4
C	-15	544	-0.6	9.1
D	-38	620	0.1	7.2
E	-9	517	0.3	9.4
F	-64	576	0.01	4.3
G	-53	528	-0.04	4.2
H	-2	593	0.1	3.4
I	-36	509	0.3	3.2
J	-0.4	563	-0.1	4.7
K	-80	565	-0.1	2.6

TABLE M-3

RESULTS WITH X, Y ERRORS

Position Error (FT)	Horiz. or Vert. cmds	Failures				False Alarms				
		80 Straight Collisions (Scenarios A, B, C, D)		20 Turning (E)		80 Straight (F, G, H, I)		20-90° turns (J)		20-45° turns (K)
		Inner	Middle	Inner	Middle	4000'	6000'	4000'	6000'	
(180 knot vs. 100 knot)										
250	V	0	33	20	0	0	-	7	-	0
250	H	0	40	20	0	0	-	13	-	0
750	V	0	25	16	4	11	-	11	-	0
750	H	0	37	17	3	8	-	7	-	0
1000	V	1	24	18	2	23	-	13	0	1
1000	H	4	32	18	2	15	0	9	-	2
2000	V	12	30	13	5	46	-	15	4	8
2000	H	16	30	18	2	40	3	12	-	5
(250 knot vs. 250 knot)										
250	V	0	15	20	0	0	-	6	-	0
1000	.V	0	28	20	0	22	-	9	-	7
2000	V	11	36	19	1	41	-	10	-	5

TABLE M-4

TRACKER STATISTICS FOR RPU = 250 FT.

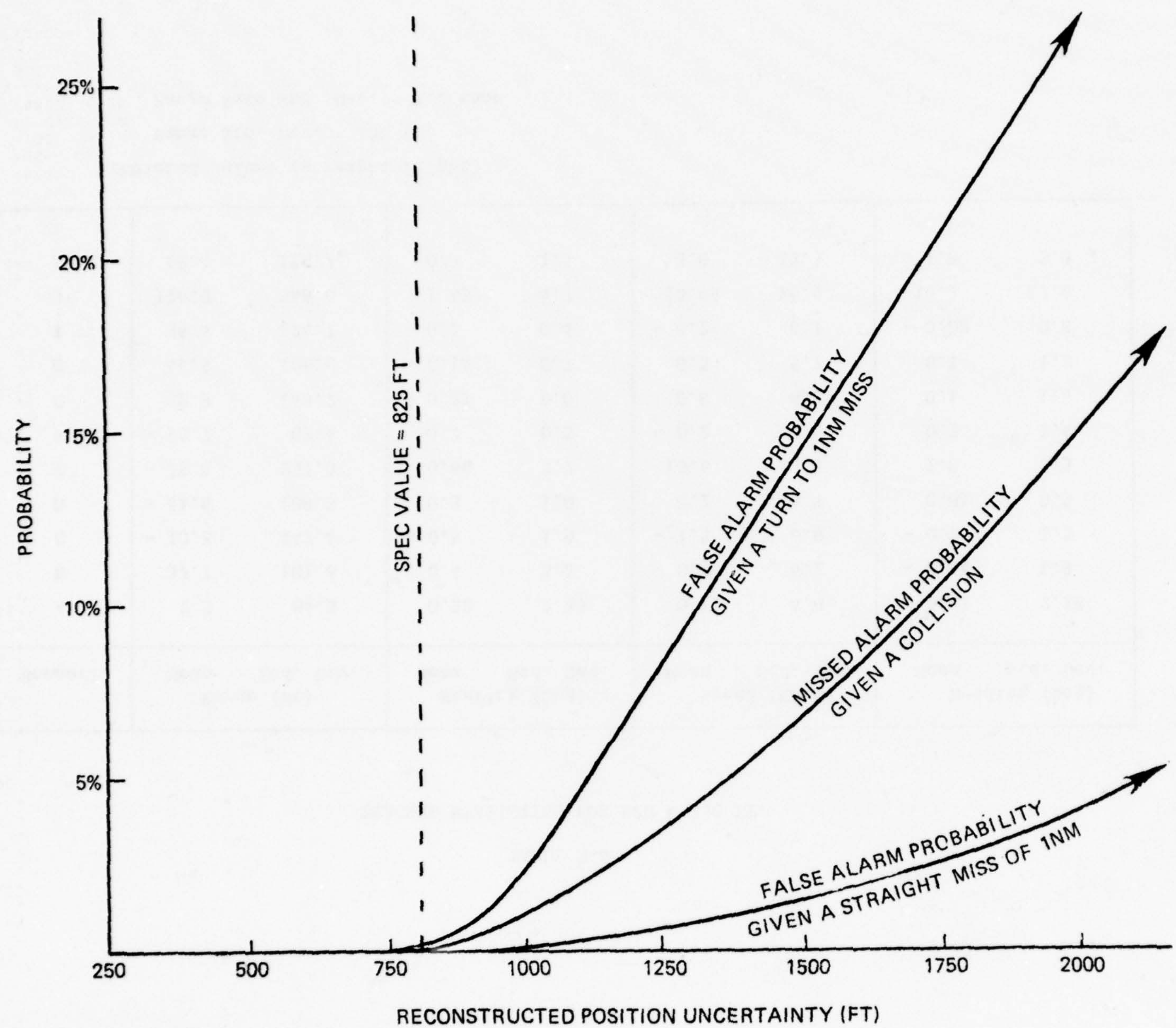
Scenario	Range (Ft)		Bearing (Deg)		Speed (Knot)		Heading (Deg)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
A	2.3	84.3	0.22	2.85	0.13	4.0	- 0.01	2.28
B	37.7	101.6	0.4	3.2	- 0.5	4.2	- 0.16	1.9
C	- 10.8	142.4	- 0.5	1.9	- 1.5	6.0	- 0.2	1.3
D	- 61.6	108.5	0.3	1.0	0.2	4.7	0.01	0.9
E	- 75.8	257.0	0.66	3.7	10.6	23.5	1.8	8.3
F	- 13.7	63.4	0.2	0.5	- 0.2	3.5	0.2	1.4
G	2.9	145.7	- 0.25	0.8	0.8	6.8	0.1	1.4
H	46.5	106.6	- 0.14	0.7	0.5	5.7	0.1	1.2
I	36.4	124.7	- 0.1	0.4	- 0.2	6.7	- 0.02	0.8
J	128.0	346.6	1.85	4.7	10.45	26.9	-10.2	17.6
K	48.4	129.7	0.5	1.5	3.0	13.3	- 1.8	5.3

Predicted values (straight flight):

Range Std. Dev. = 150 ft.

Range Rate Std. Dev. = 7.2 knot

BCAS PERFORMANCE



BCAS PERFORMANCE

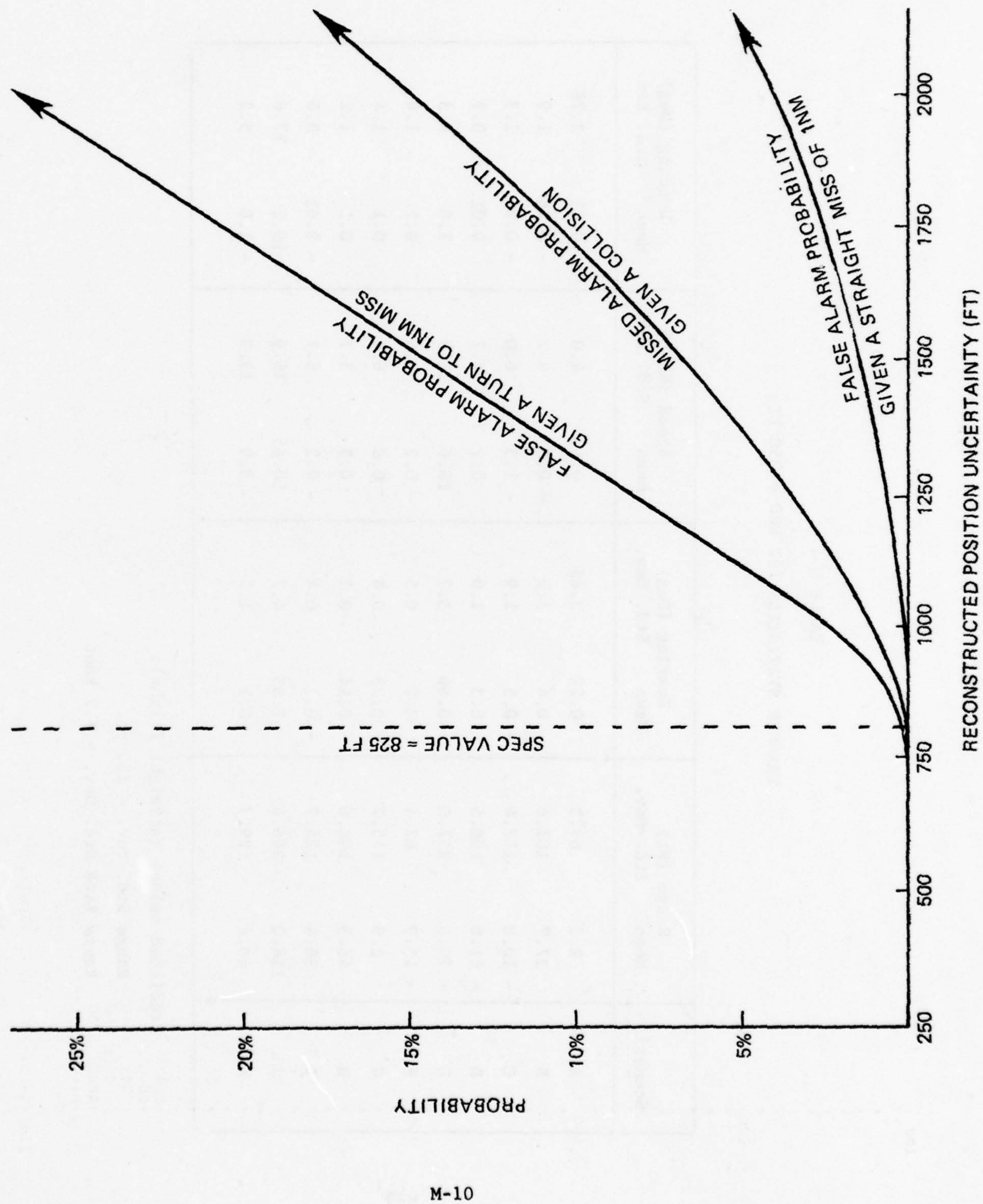
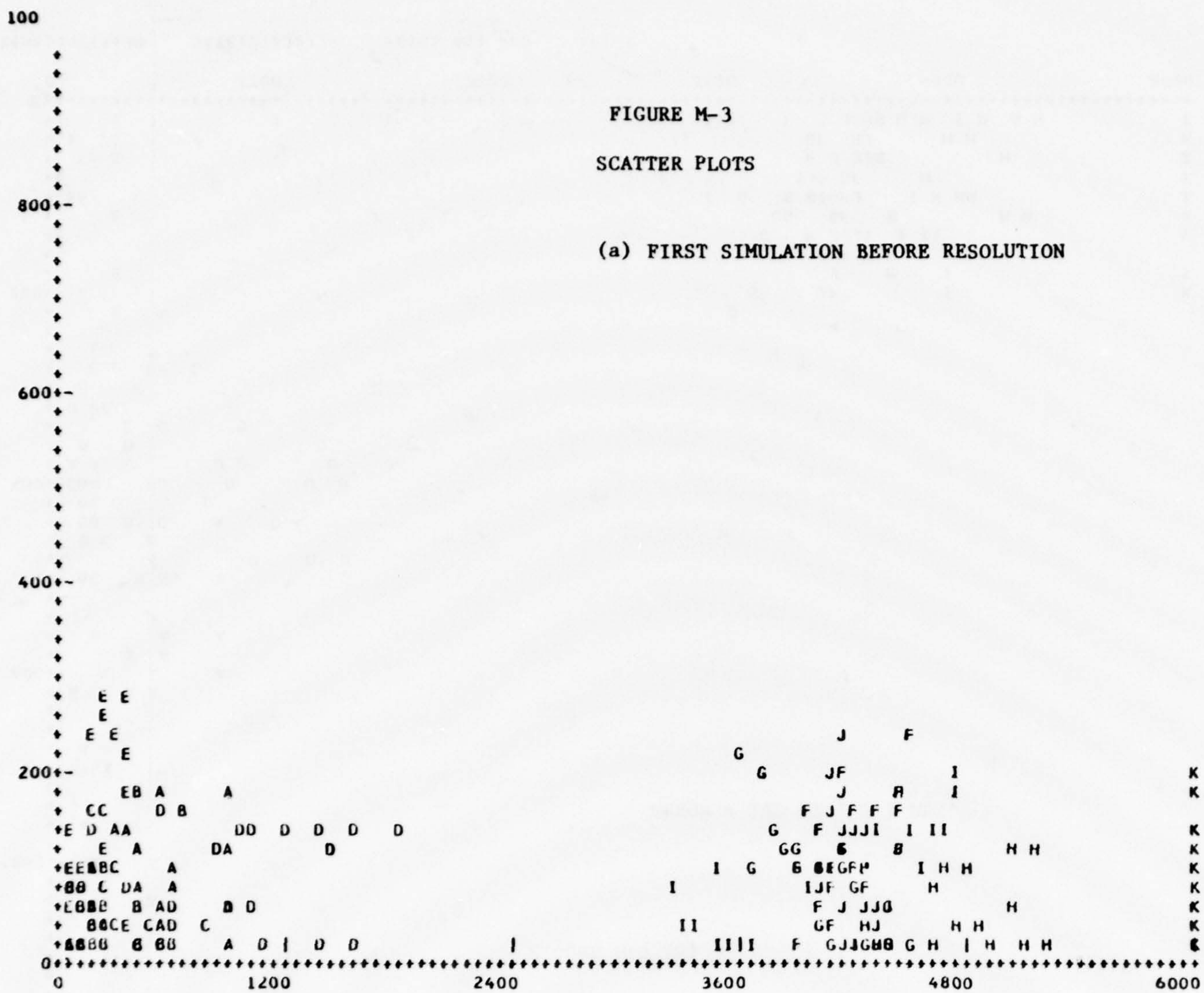


FIGURE M-3

SCATTER PLOTS

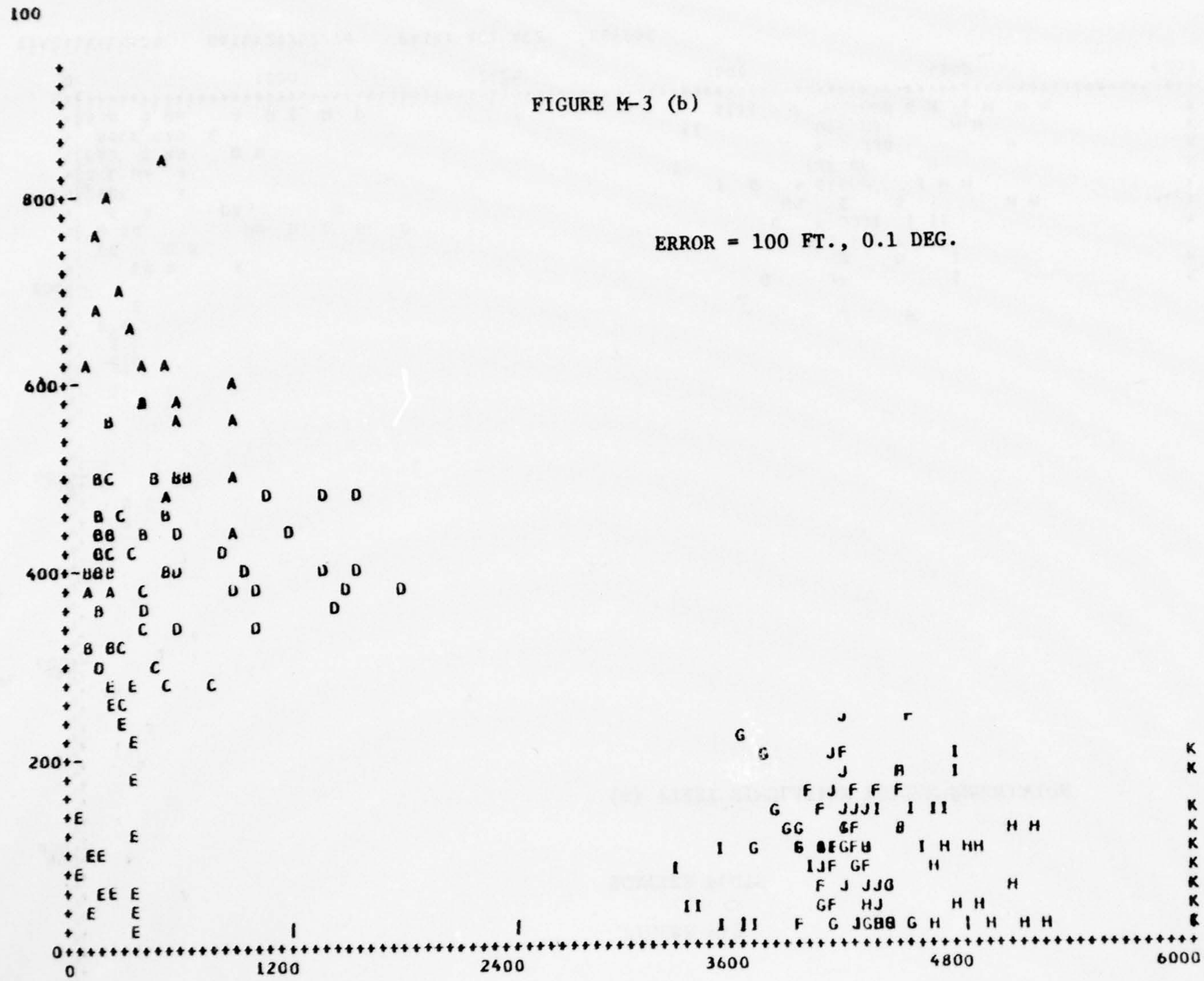
(a) FIRST SIMULATION BEFORE RESOLUTION



TIME:14:14:39 DATE:27/02/78 PAIR: AC1 AC2 BEFORE

FIGURE M-3 (b)

ERROR = 100 FT., 0.1 DEG.



TIME:14:14:39 DATE:27/02/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (c)

ERROR = 100 FT., 1 DEG.

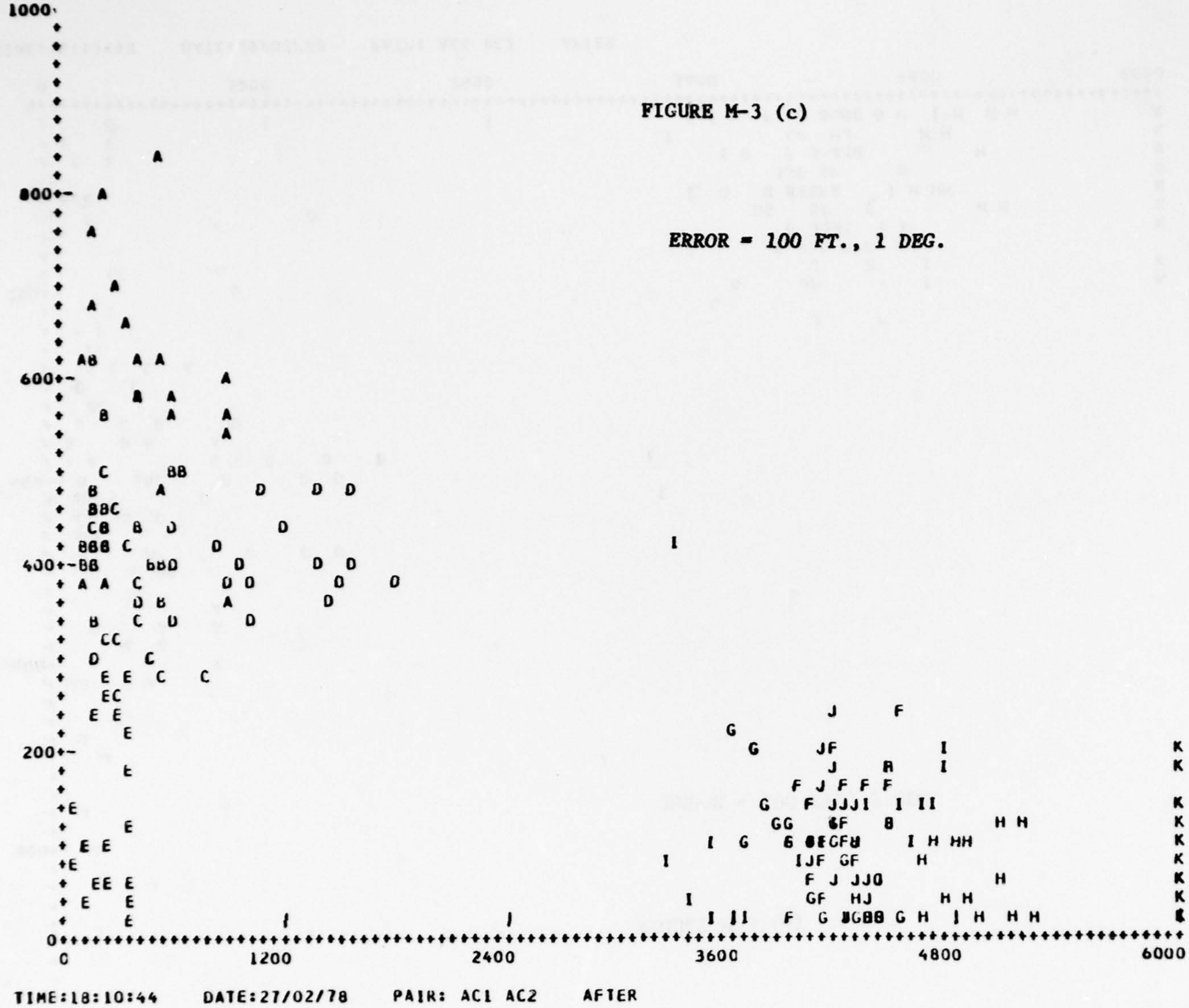
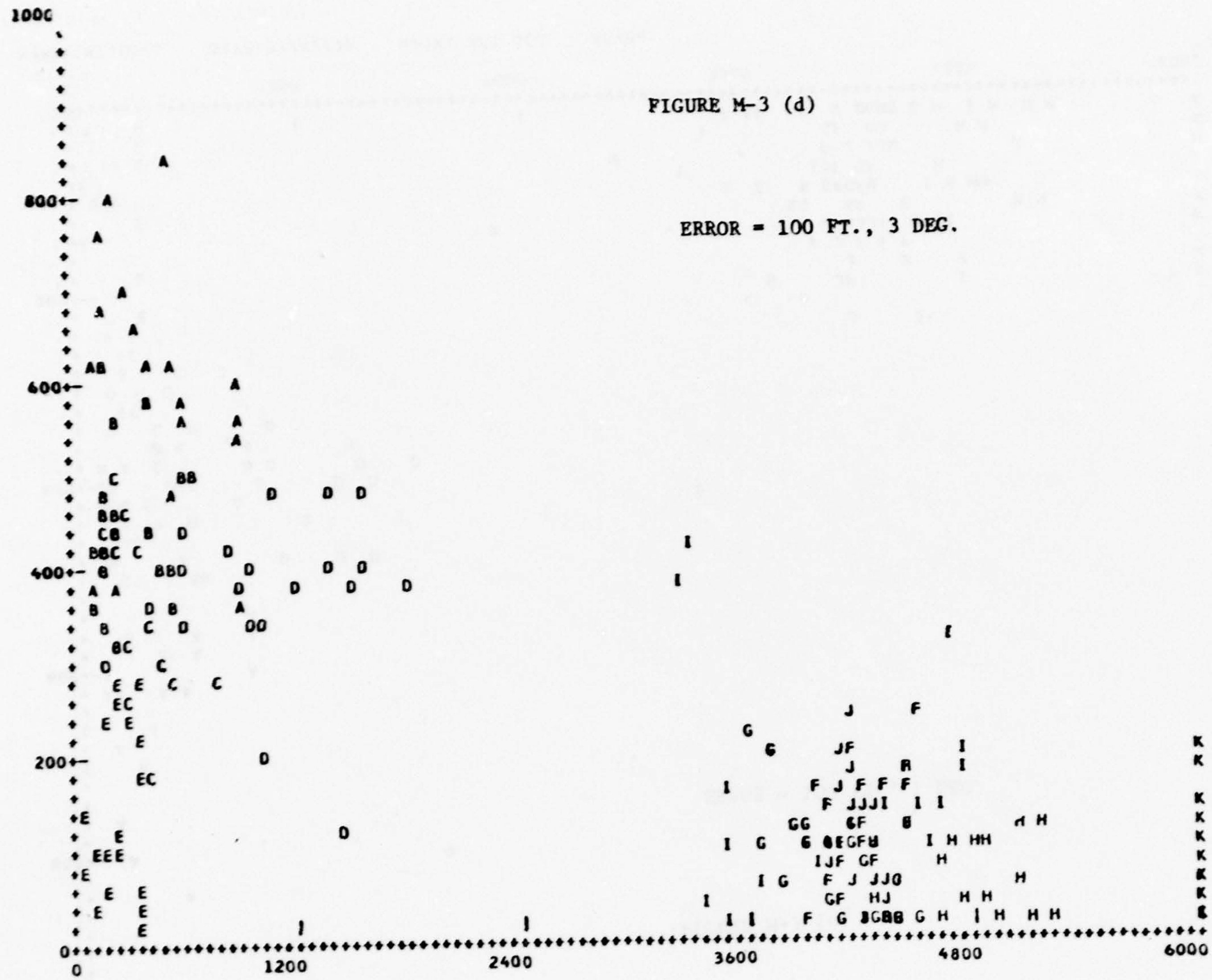


FIGURE M-3 (d)

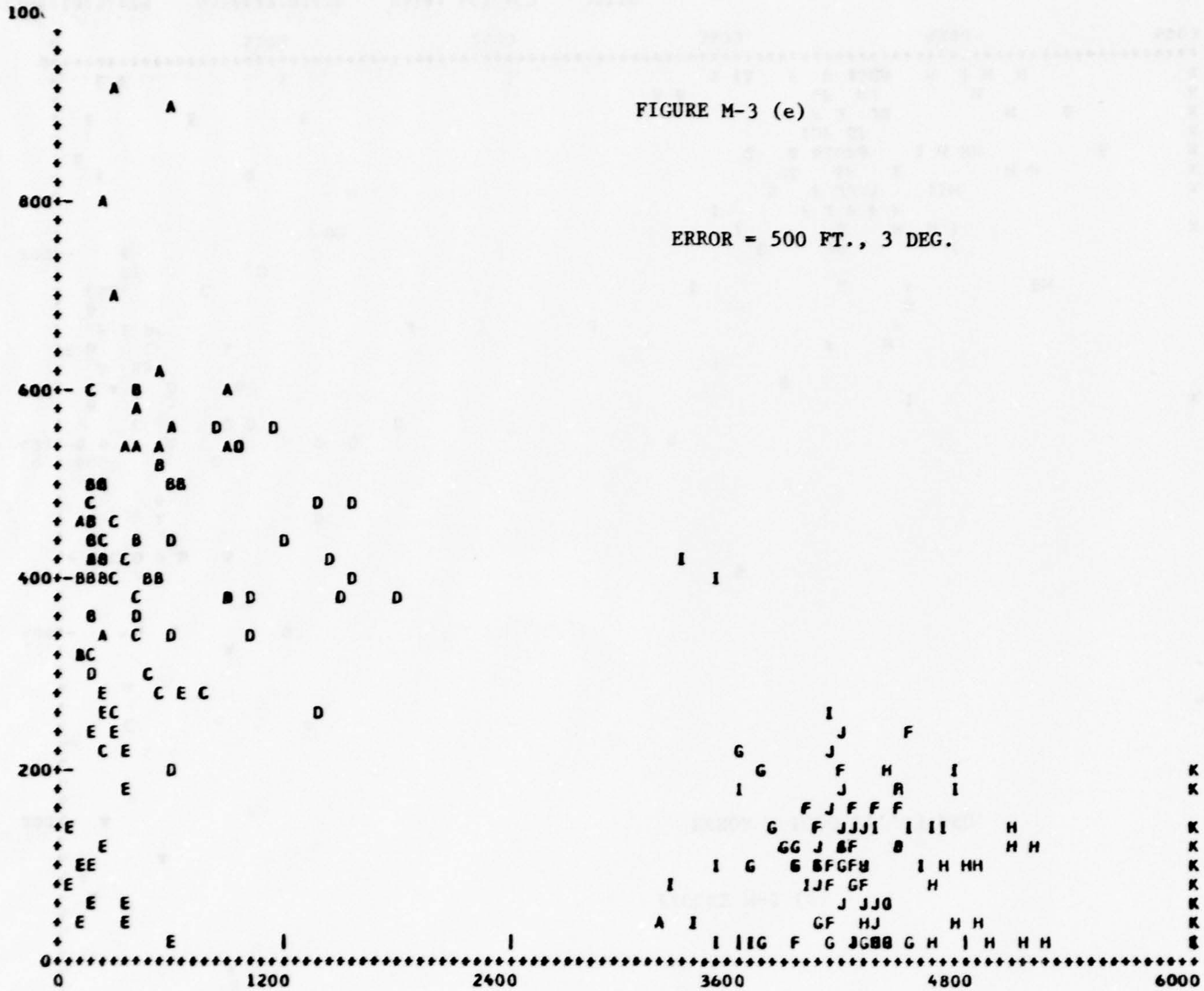
ERROR = 100 FT., 3 DEG.



TIME:10:47:43 DATE:28/02/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (e)

ERROR = 500 FT., 3 DEG.



TIME:10:54:45 DATE:28/02/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (f)

ERROR = 1000 FT., 3 DEG.

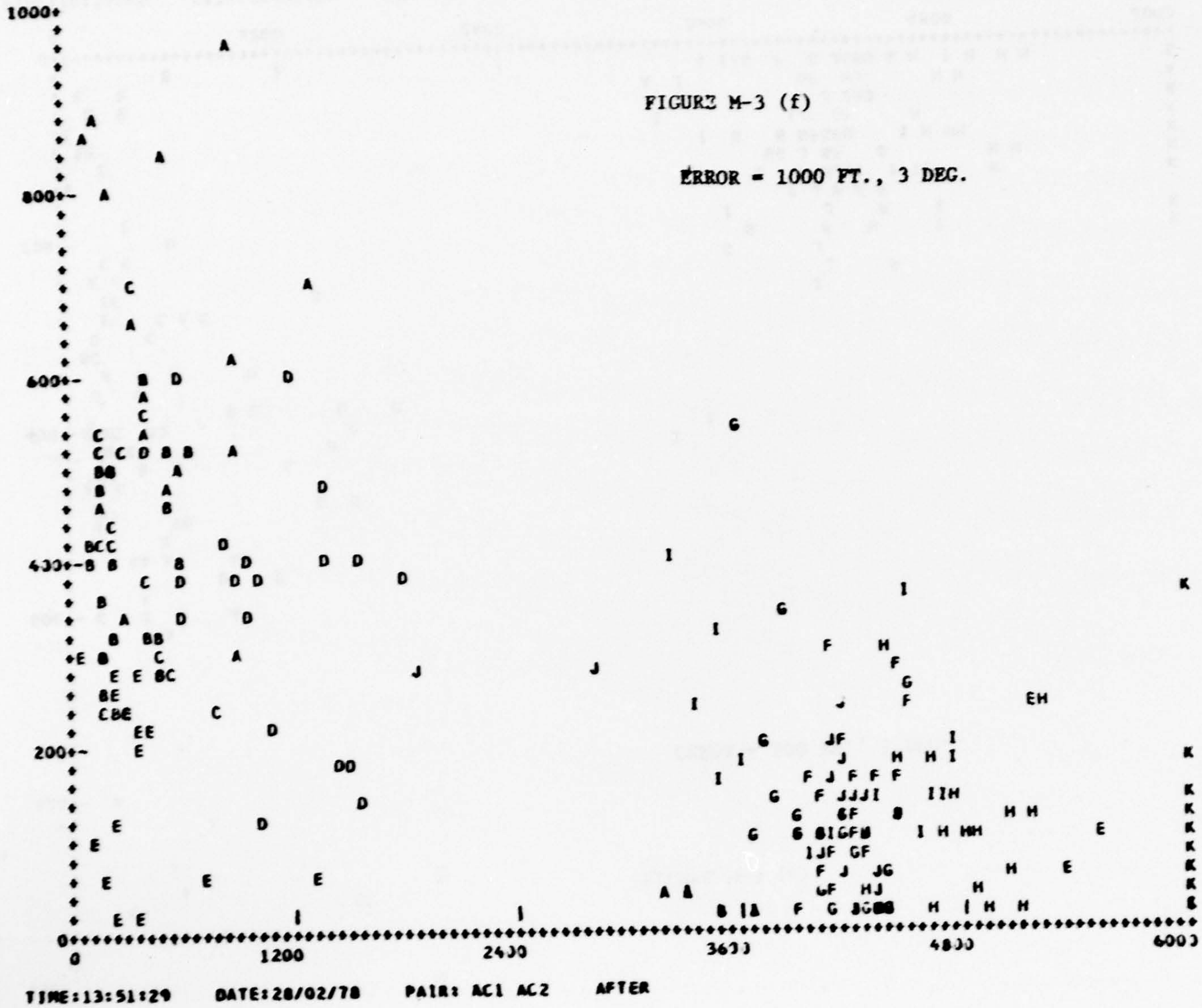
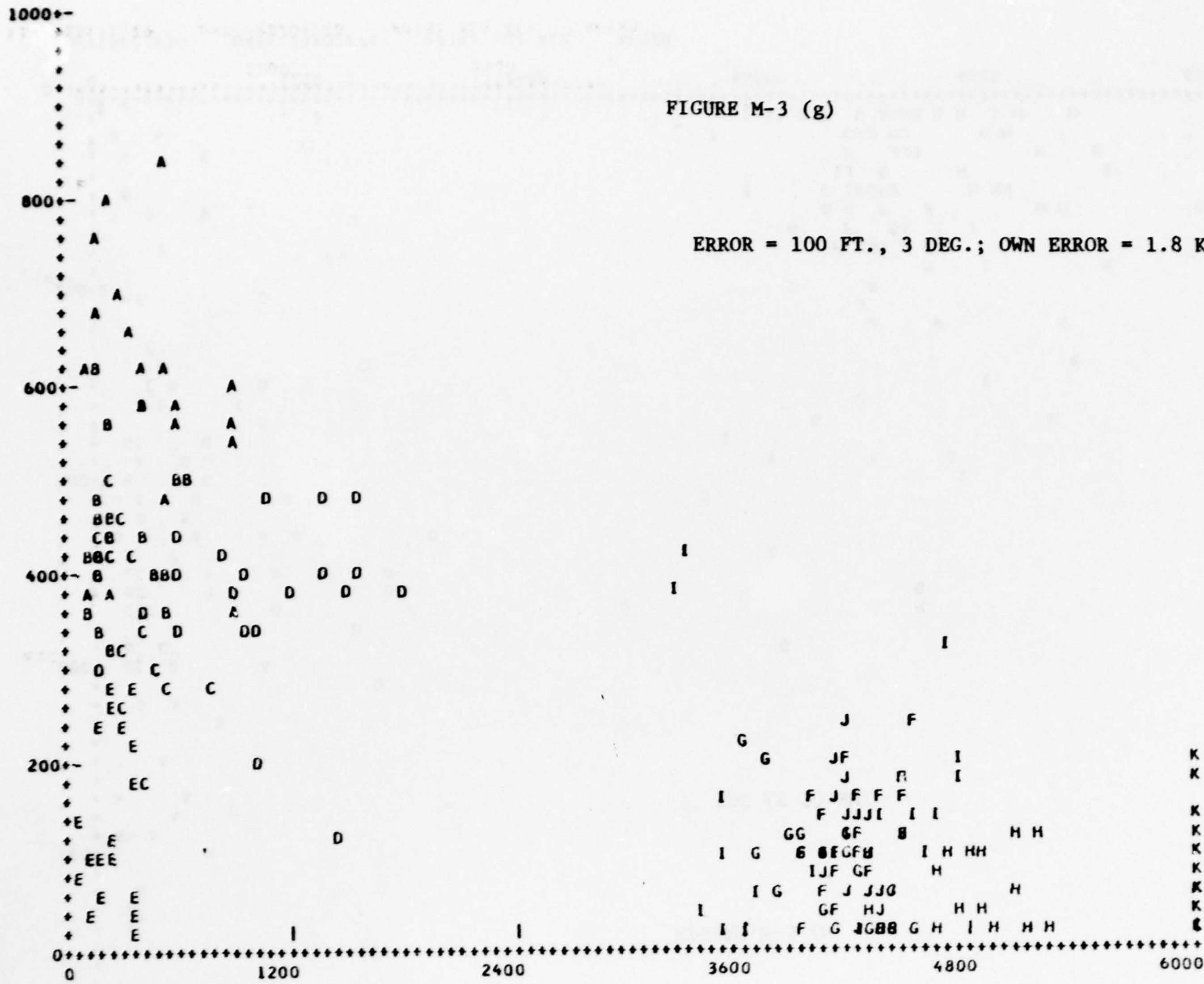


FIGURE M-3 (g)

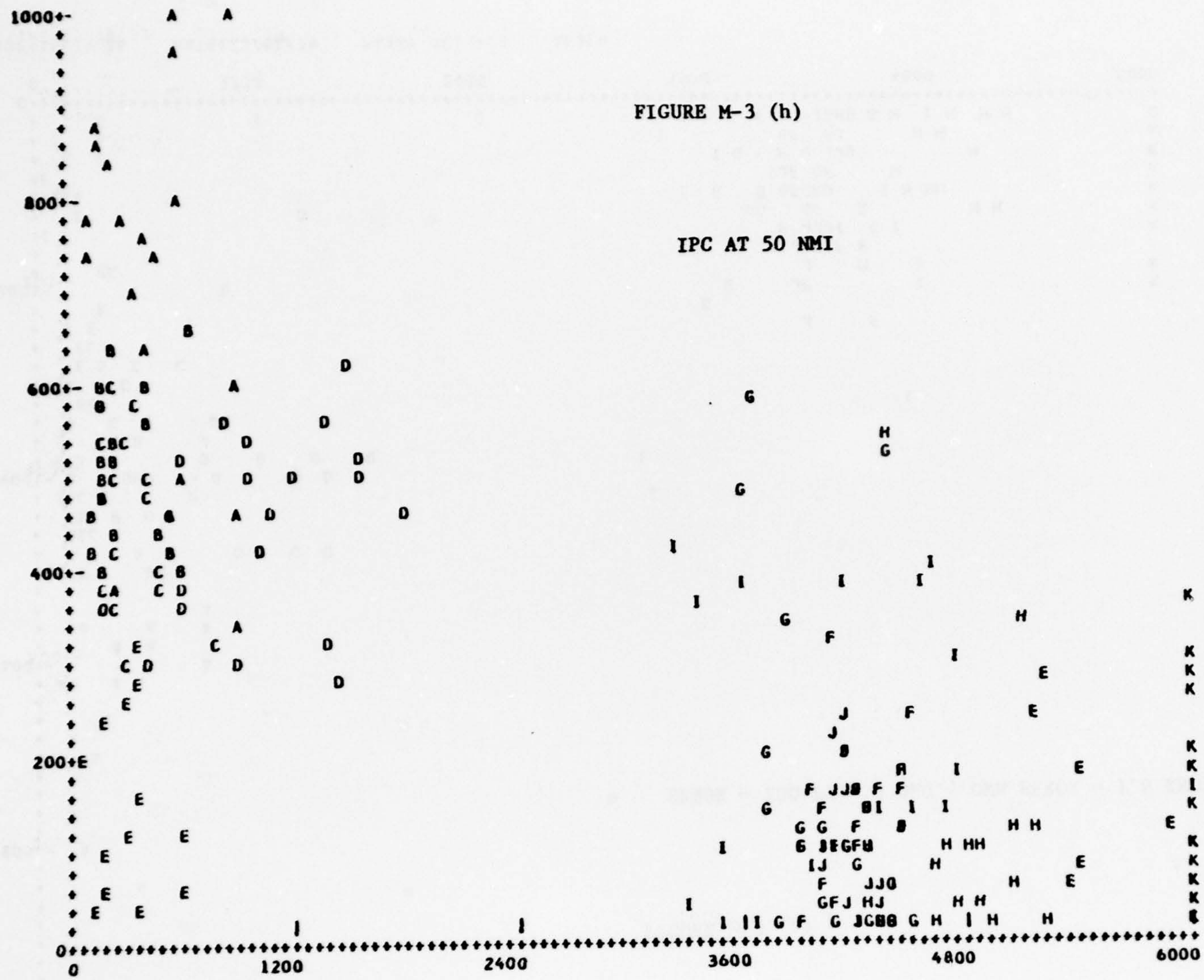
ERROR = 100 FT., 3 DEG.; OWN ERROR = 1.8 KNOTS, 3 DEG.



TIME:16:24:26 DATE:28/02/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (h)

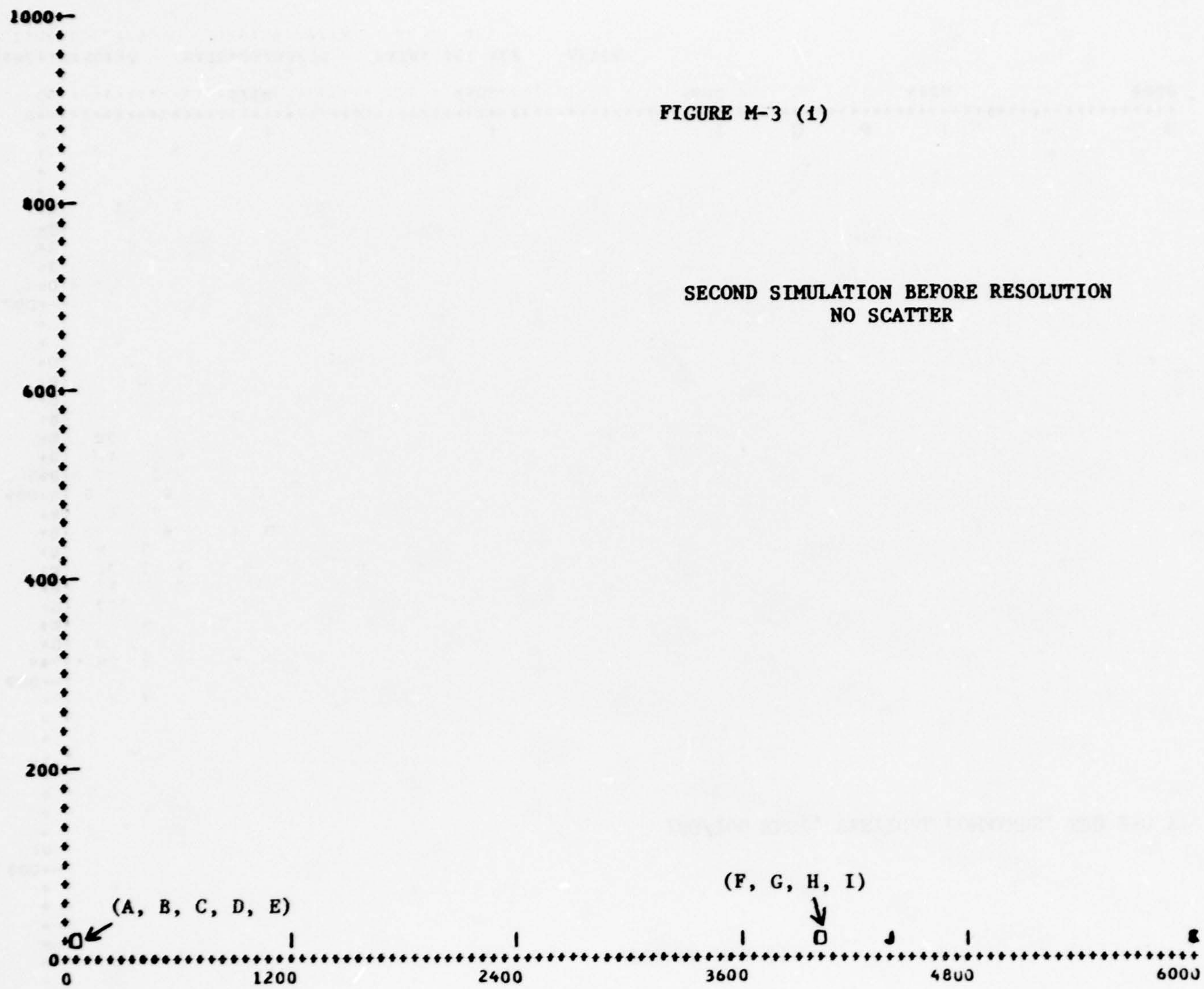
IPC AT 50 NMI



TIME:18:27:50 DATE:28/02/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (1)

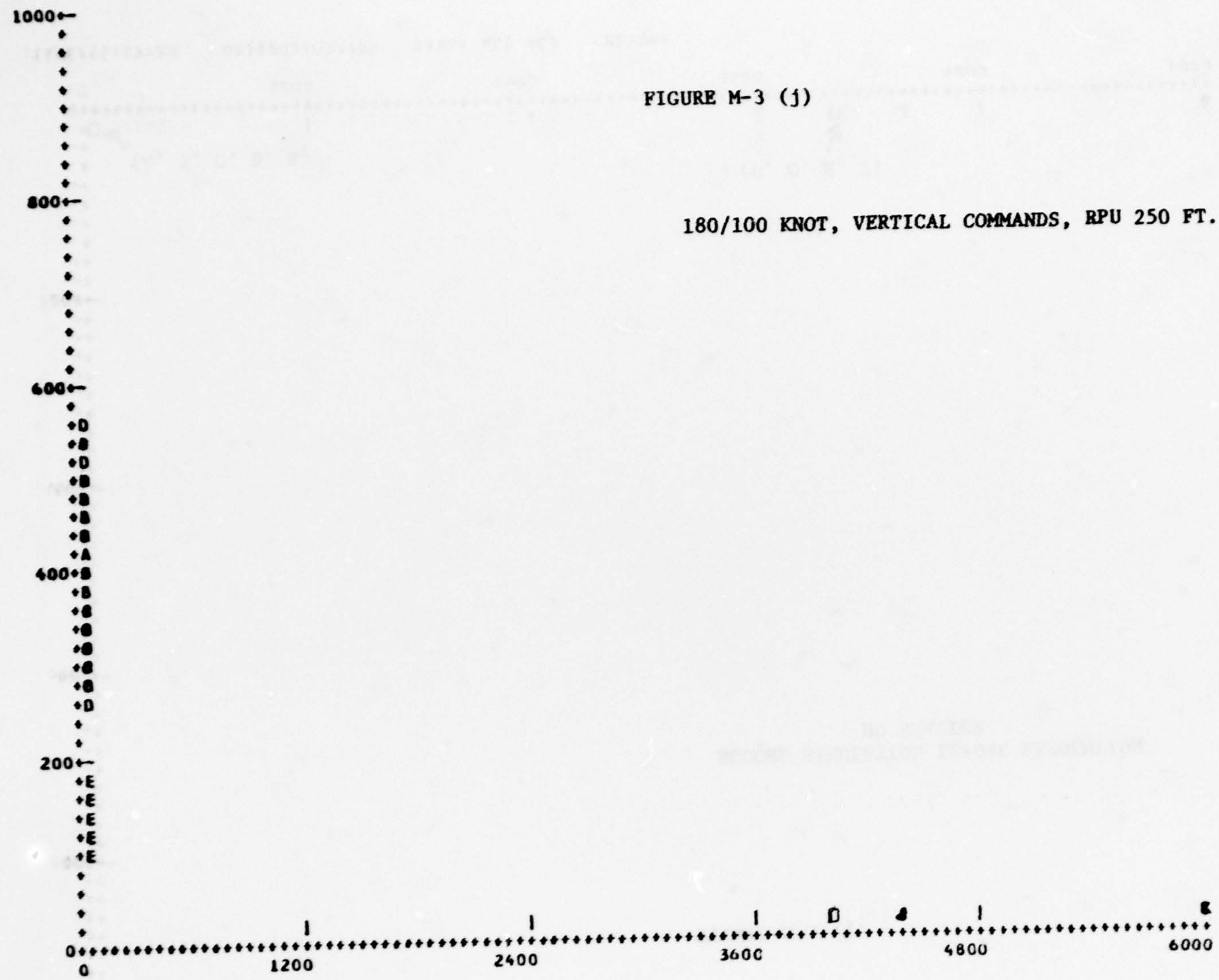
SECOND SIMULATION BEFORE RESOLUTION
NO SCATTER



TIME:15:29:23 DATE:03/03/78 PAIR: AC1 AC2 BEFORE

FIGURE M-3 (j)

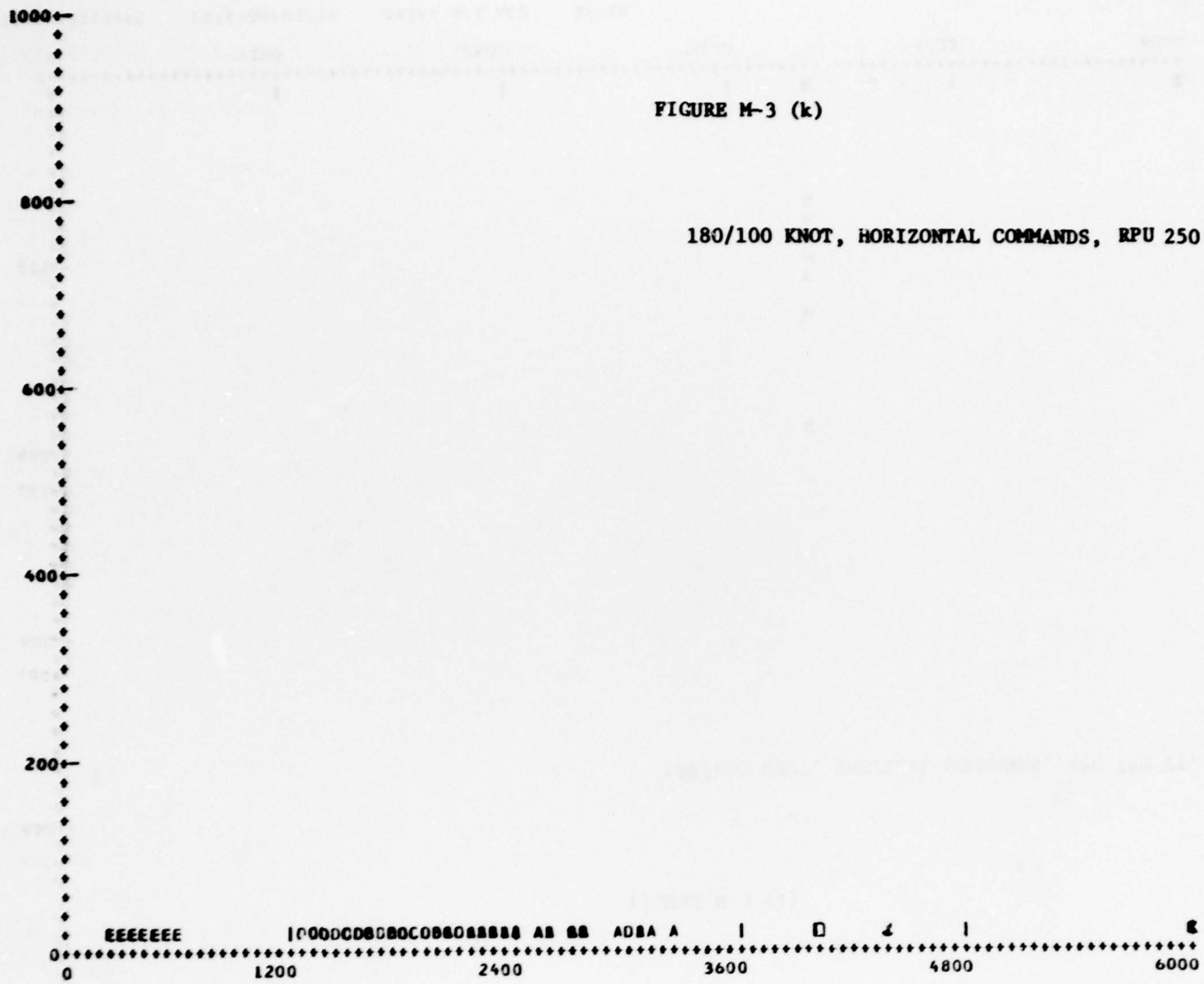
180/100 KNOT, VERTICAL COMMANDS, RPU 250 FT.



TIME:13:50:18 DATE:03/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (k)

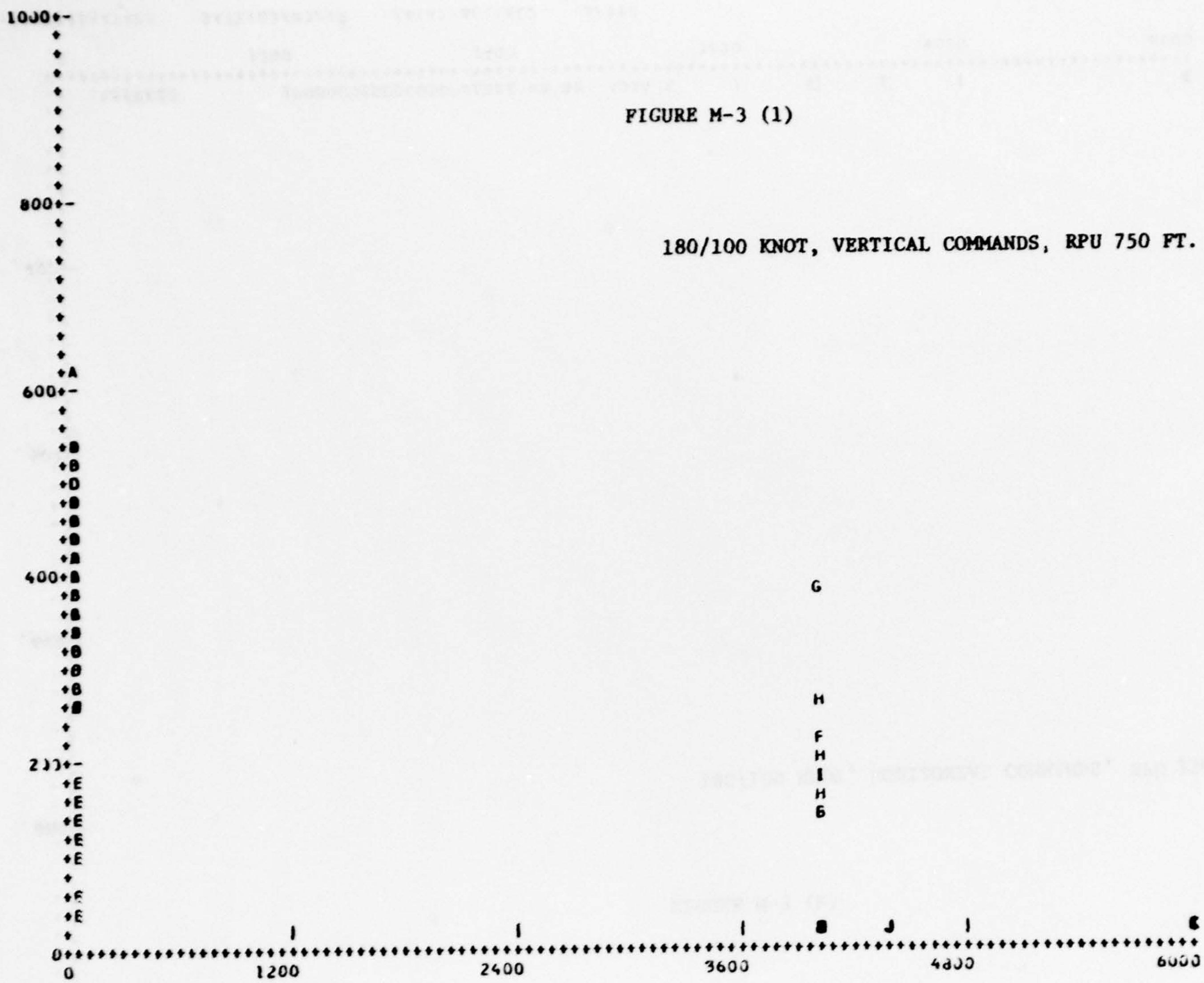
180/100 KNOT, HORIZONTAL COMMANDS, RPU 250 FT.



TIME:15:29:23 DATE:03/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (1)

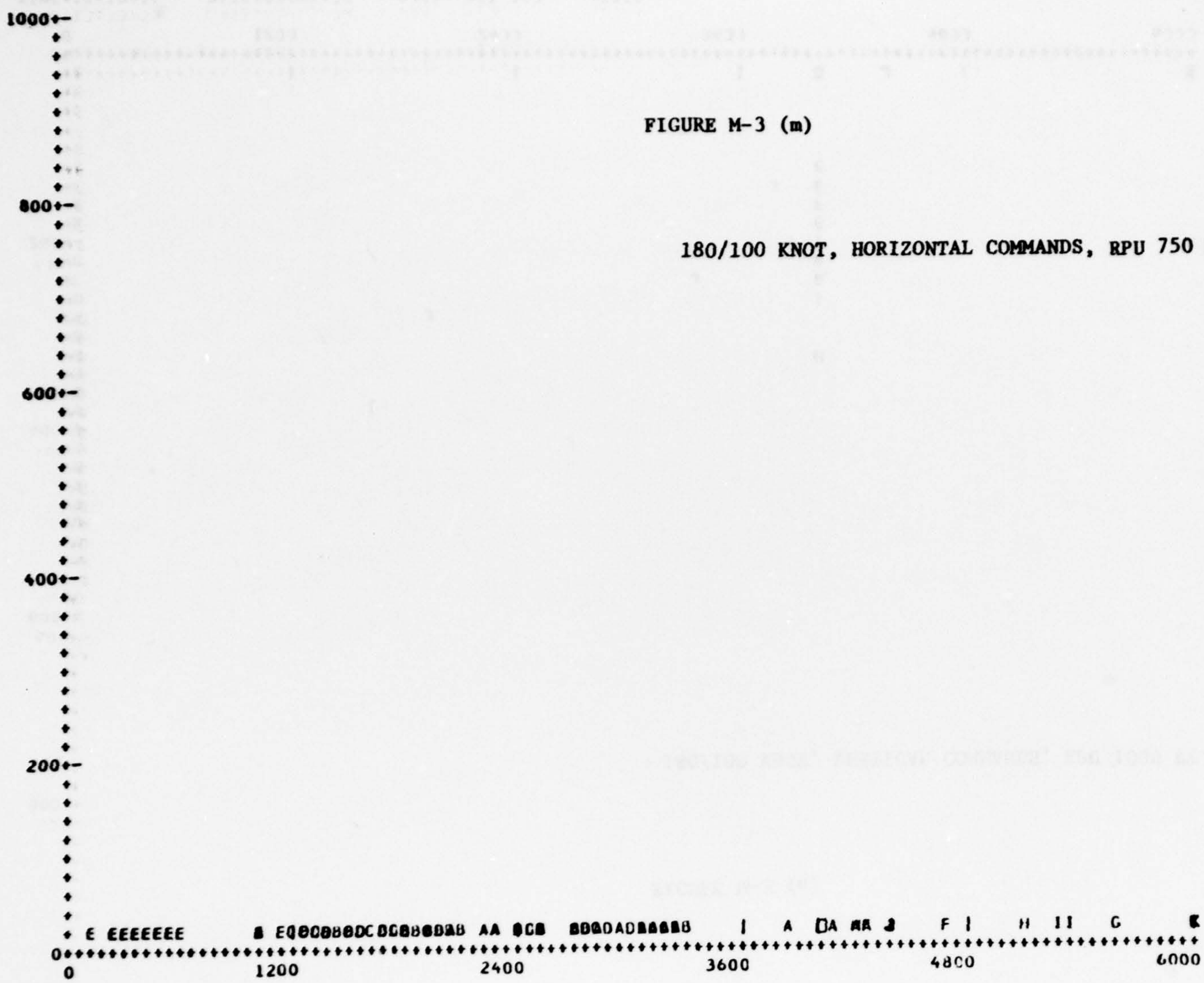
180/100 KNOT, VERTICAL COMMANDS, RPU 750 FT.



TIME:13:13:55 DATE:06/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (m)

180/100 KNOT, HORIZONTAL COMMANDS, RPU 750 FT.



TIME:13:05:56 DATE:06/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (n)

180/100 KNOT, VERTICAL COMMANDS, RPU 1000 FT.

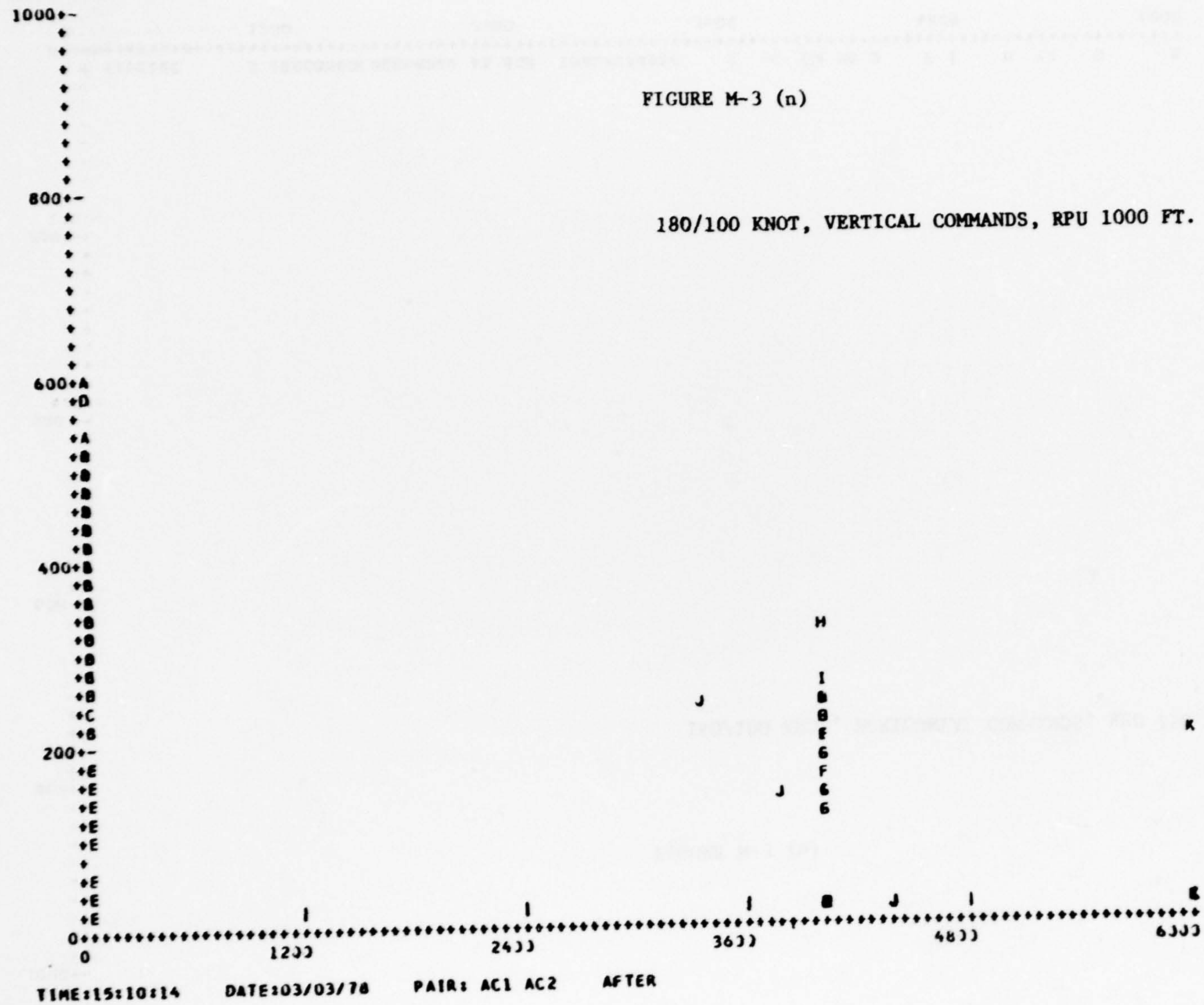


FIGURE M-3 (o)

180/100 KNOT, HORIZONTAL COMMANDS, RPU 1000 FT.

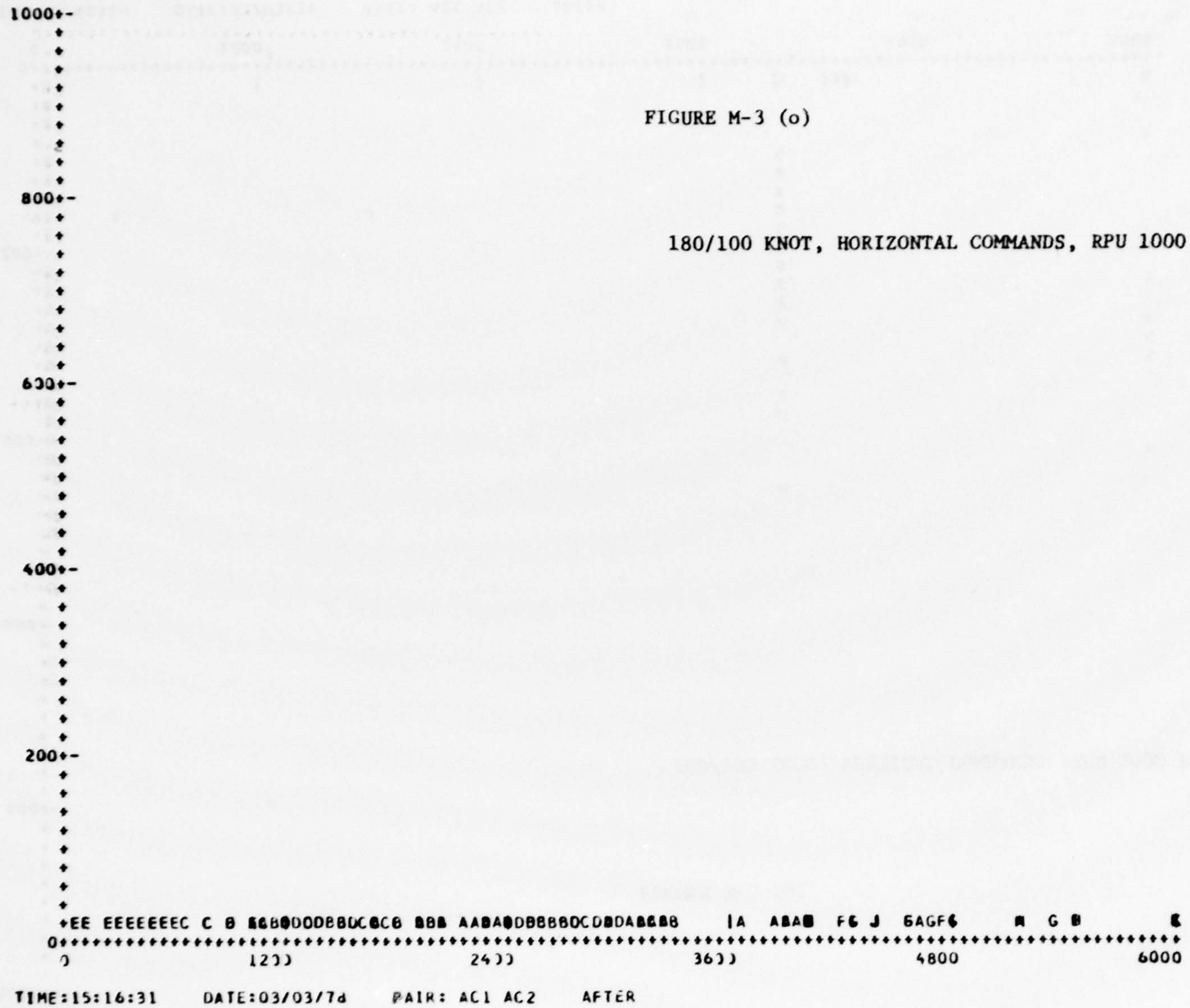


FIGURE M-3 (p)

180/100 KNOT, VERTICAL COMMANDS, RPU 2000 FT.

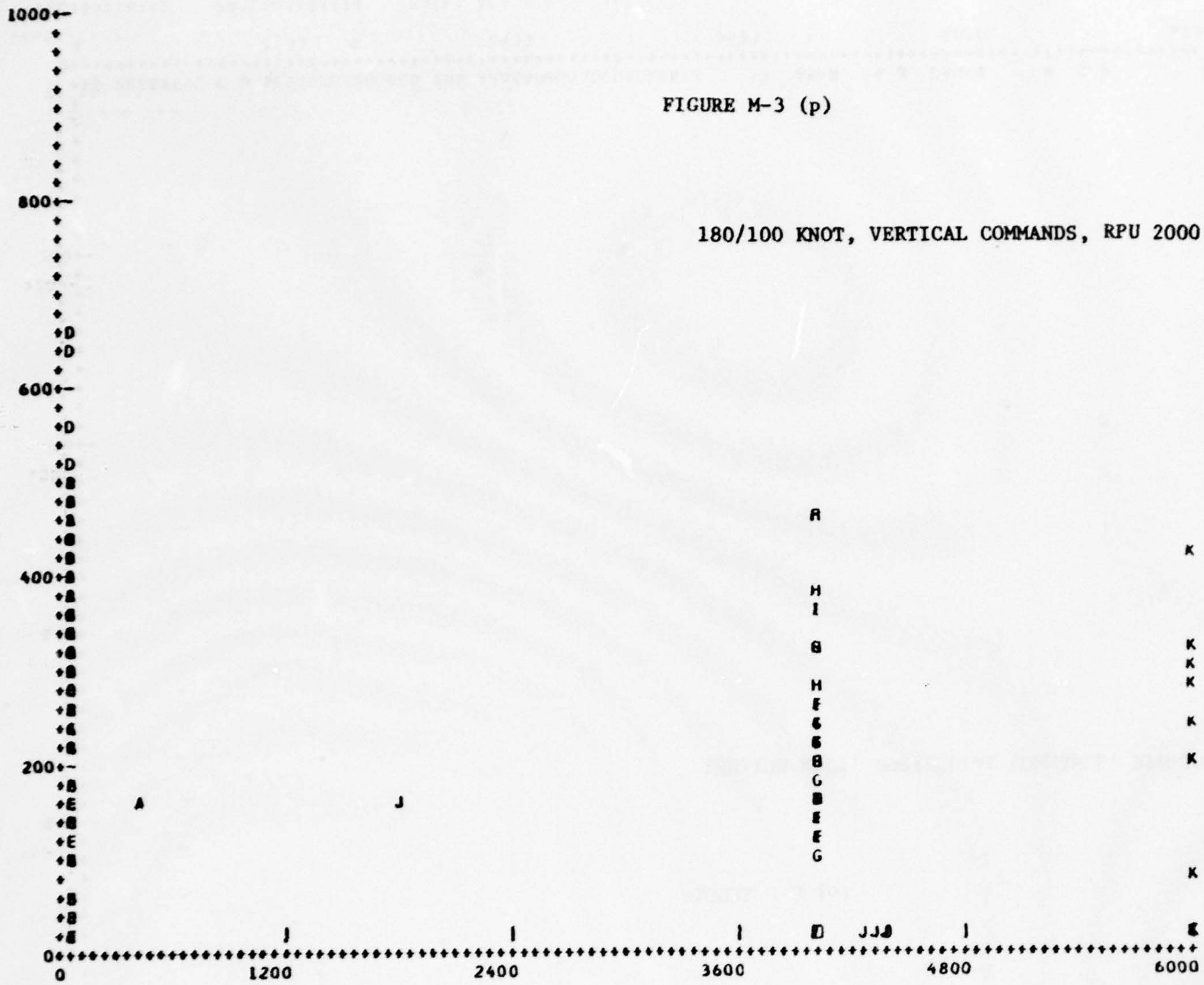
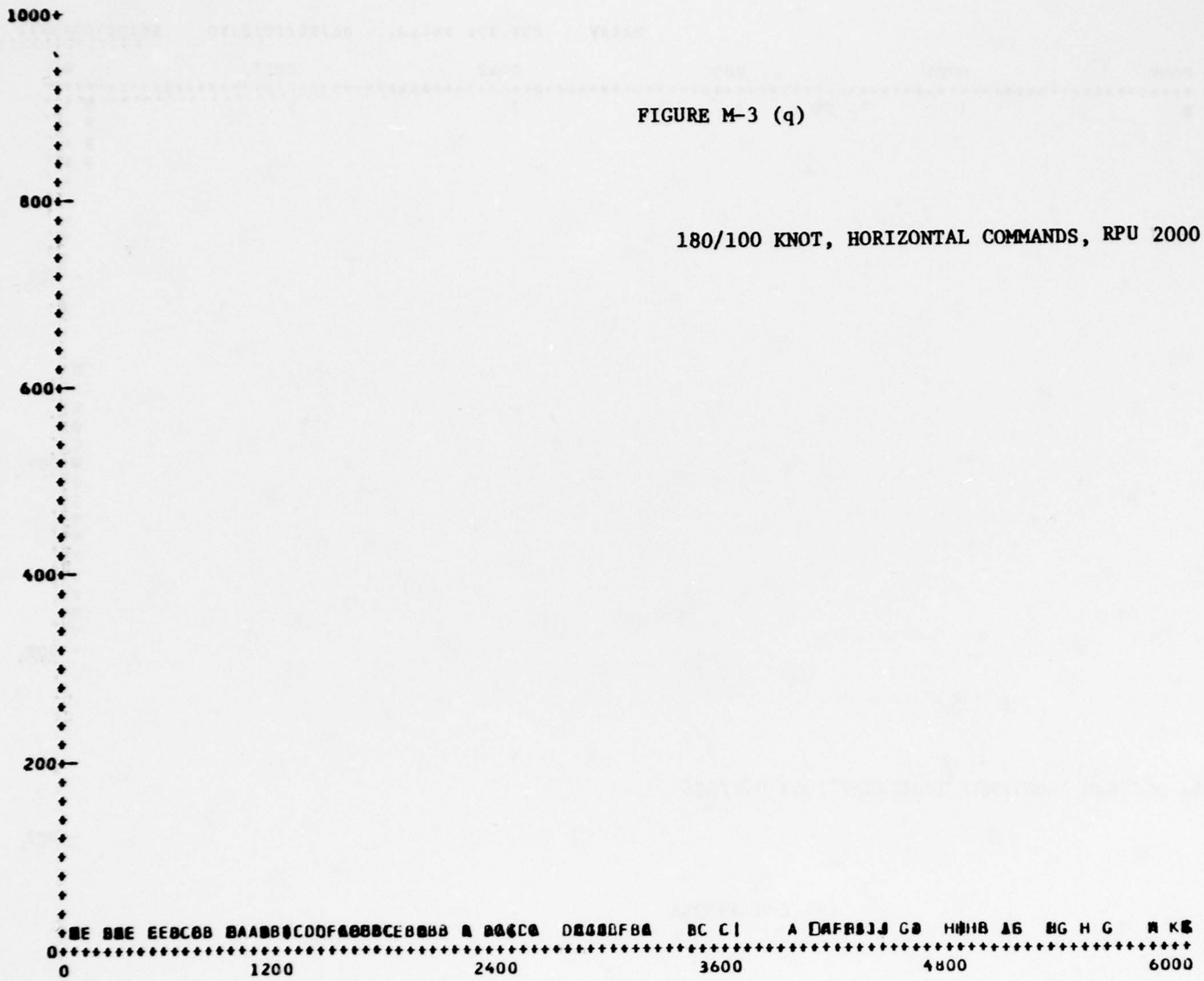


FIGURE M-3 (q)

180/100 KNOT, HORIZONTAL COMMANDS, RPU 2000 FT.



TIME:15:23:48 DATE:03/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (r)

250/250 KNOT, VERTICAL COMMANDS, RPU 250 FT.

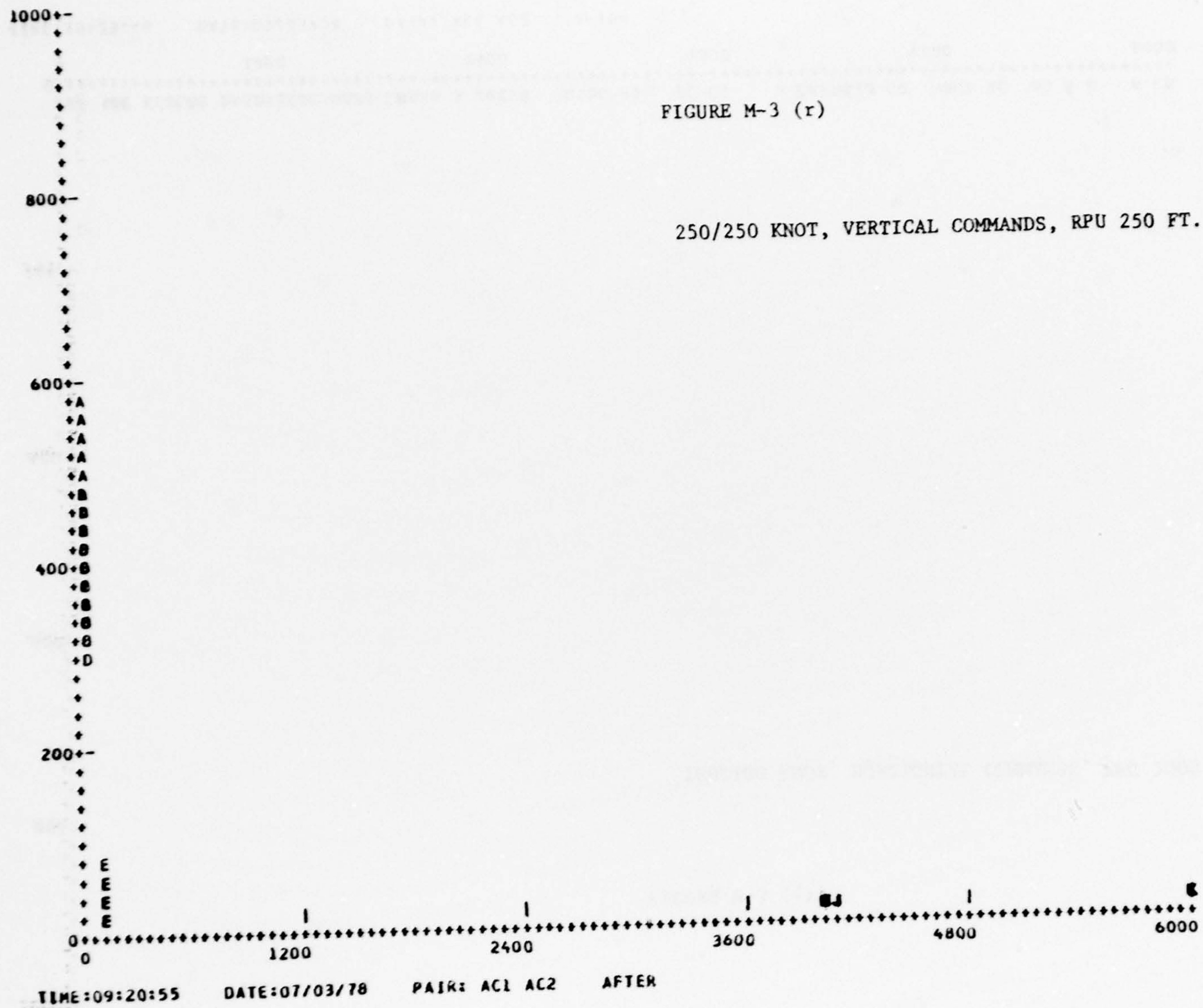
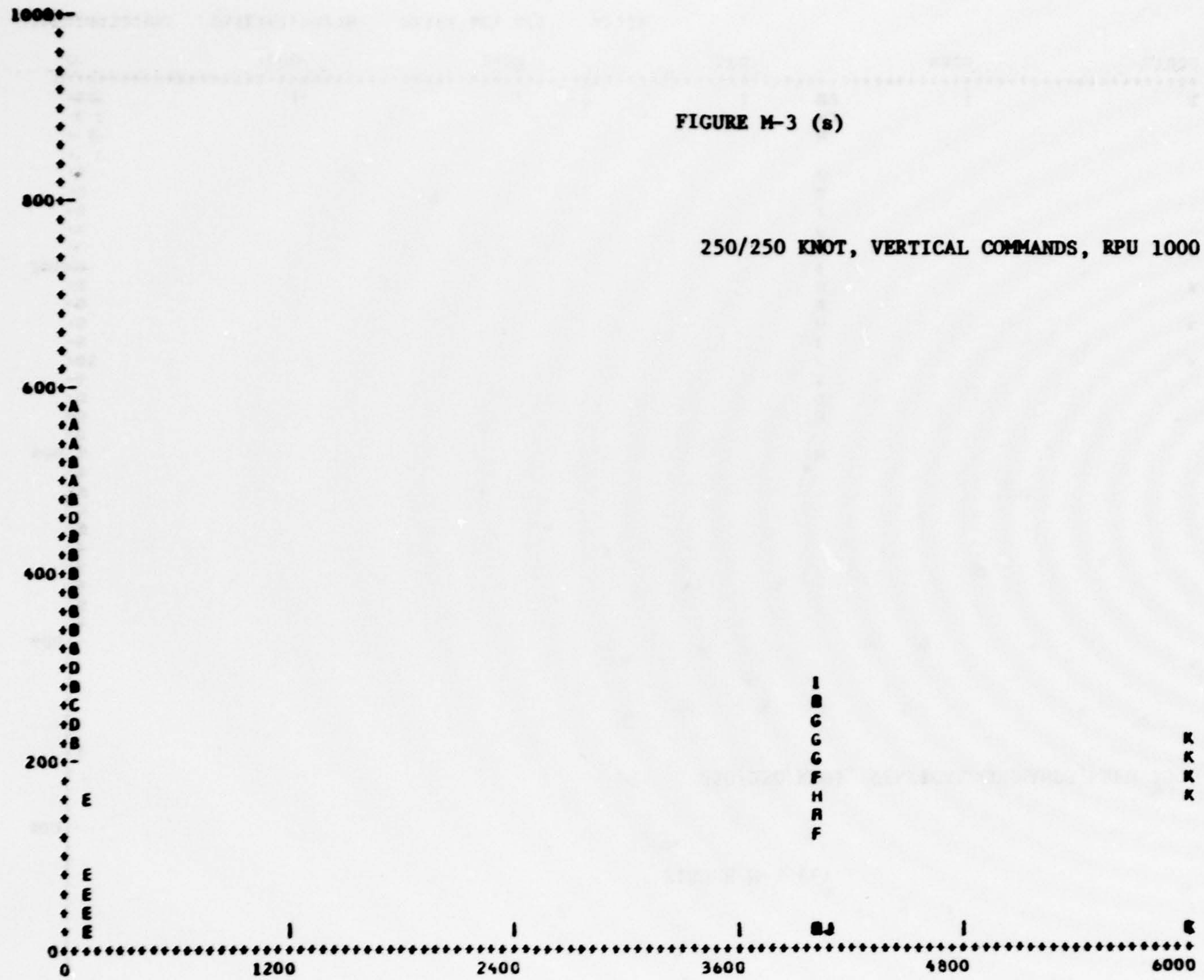


FIGURE M-3 (s)

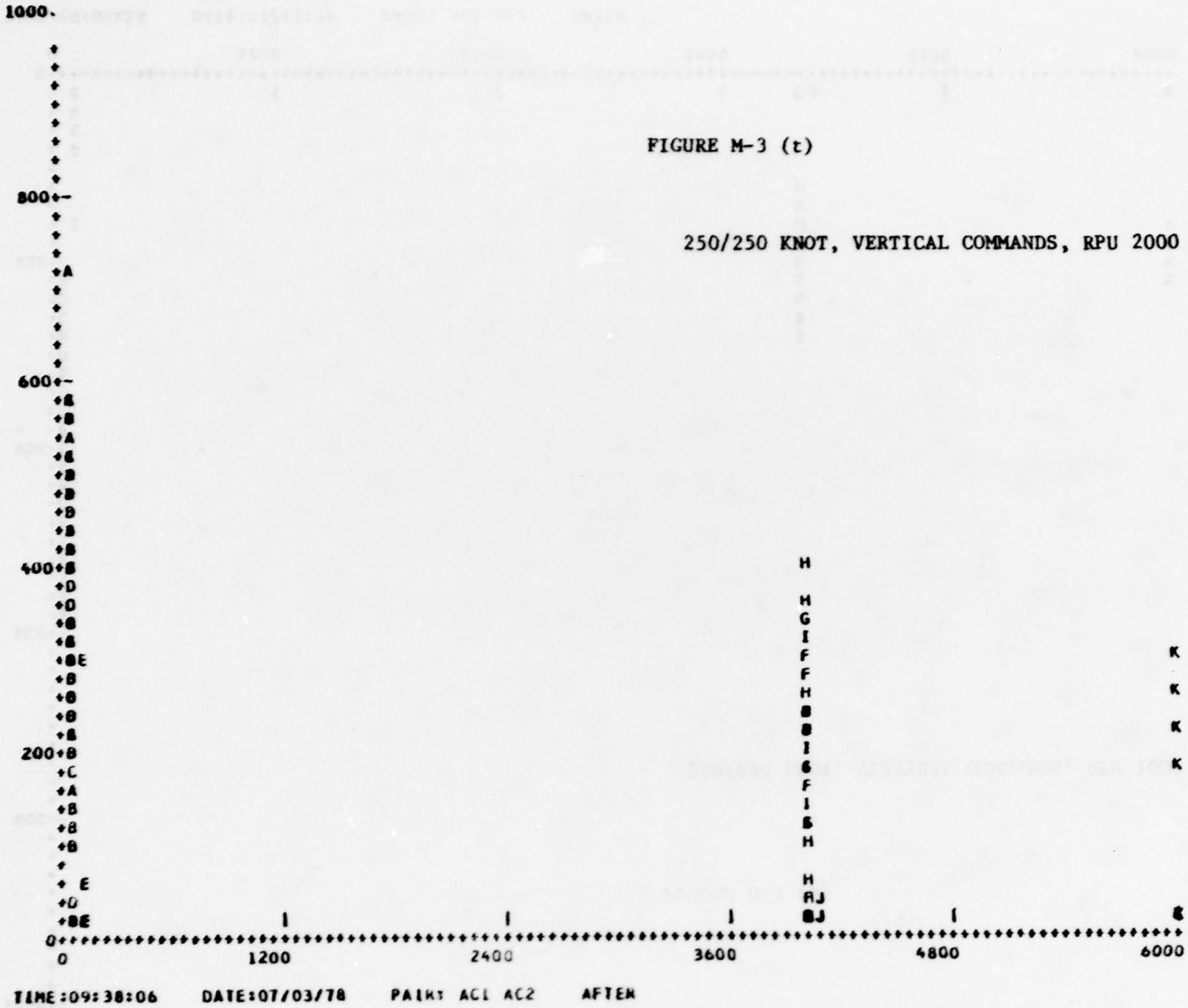
250/250 KNOT, VERTICAL COMMANDS, RPU 1000 FT.



TIME:09:03:38 DATE:07/03/78 PAIR: AC1 AC2 AFTER

FIGURE M-3 (t)

250/250 KNOT, VERTICAL COMMANDS, RPU 2000 FT.



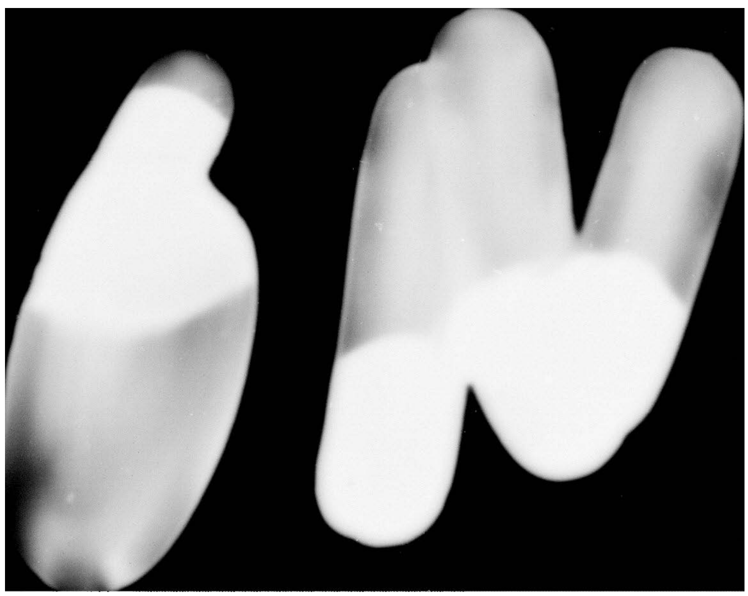
☆ U. S. GOVERNMENT PRINTING OFFICE : 1978 O - 277-521

END

DATE
FILMED

2-79

DDC



AD-A061 949 FEDERAL AVIATION ADMINISTRATION WASHINGTON D C OFFIC--ETC F/G 17/7
FAA BCAS CONCEPT. VOLUME III B. APPENDICES F - M,(U)
APR 78 E J KOENKE
UNCLASSIFIED FAA-EM-78-5-III-B NL

5 of 5
AD A
061949

END
DATE
FILMED
7-80
DTIC

A
619

SUPPLEMENTARY

INFORMATION

AD-A061949

ERRATA

Report No. FAA-EM-78-5, III-B

FAA BCAS Concept
Appendices F - M

E. J. Koenke, et al

April 1978

Page H-1, Section H.1, Line 2 should read: "...In Section H-2,..."

Page H-1, Section H.1, Line 6 should read: "In Section H.3,..."

Page H-1, Section H.1, Line 7 should read: "studied. On..."

Page H-1, Section H.1, Line 10 should read: "...In Section H.4,..."

Page H-1, Section H.2, Line 1 should read: "...in Figure H-1."

Page H-3, Paragraph 1, Line 2 should read: "...The free"

Page H-3, Paragraph 1, Line 3 should read: "space...frequency is"

Page H-3, Paragraph 1, Line 4 should read: " $\lambda = \frac{c}{f}$ ..."

Page H-3, Paragraph 1, Line 5 should read: "...array by individually"

Page H-3, Paragraph 1, Line 7 should read: "...modes. ..."

Page H-3, Paragraph 1, Line 7 should read: "...synthesis of de-"

Page H-3, Paragraph 1, Line 8 should read: "...pattern, i.e. to..."

Page H-3, Paragraph 1, Line 8 should read: "...beam, or to achieve a given"

Page H-3, Paragraph 1, Line 9 should read: "directivity, or both."

Page H-3, Section H.2.1, Line 12 should read: "...with it, which..."

Page H-4, Paragraph 1, Line 16 should read: "for d, obtaining"

Page H-10, Paragraph 3, Line 1 should read: "...computed from H.2.11..."

Page L-8A, Insert Figure L-2-1 as page L-8A.

Date Issued: June 1979
Attachment

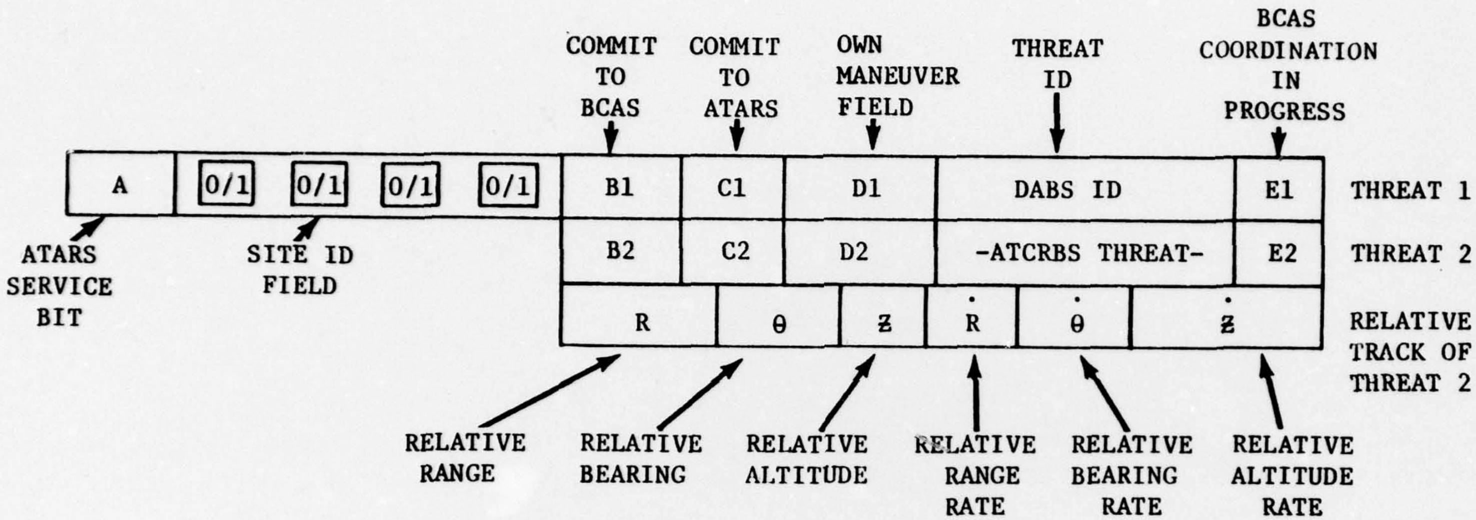


FIGURE L-2-1
THE CONFLICT INDICATOR REGISTER (CIR)